"6" HOW's + WHY's

4-8-69
R. LARSON

Basic Objectives for LM Powered-Landing Guidance-and-Navigation System

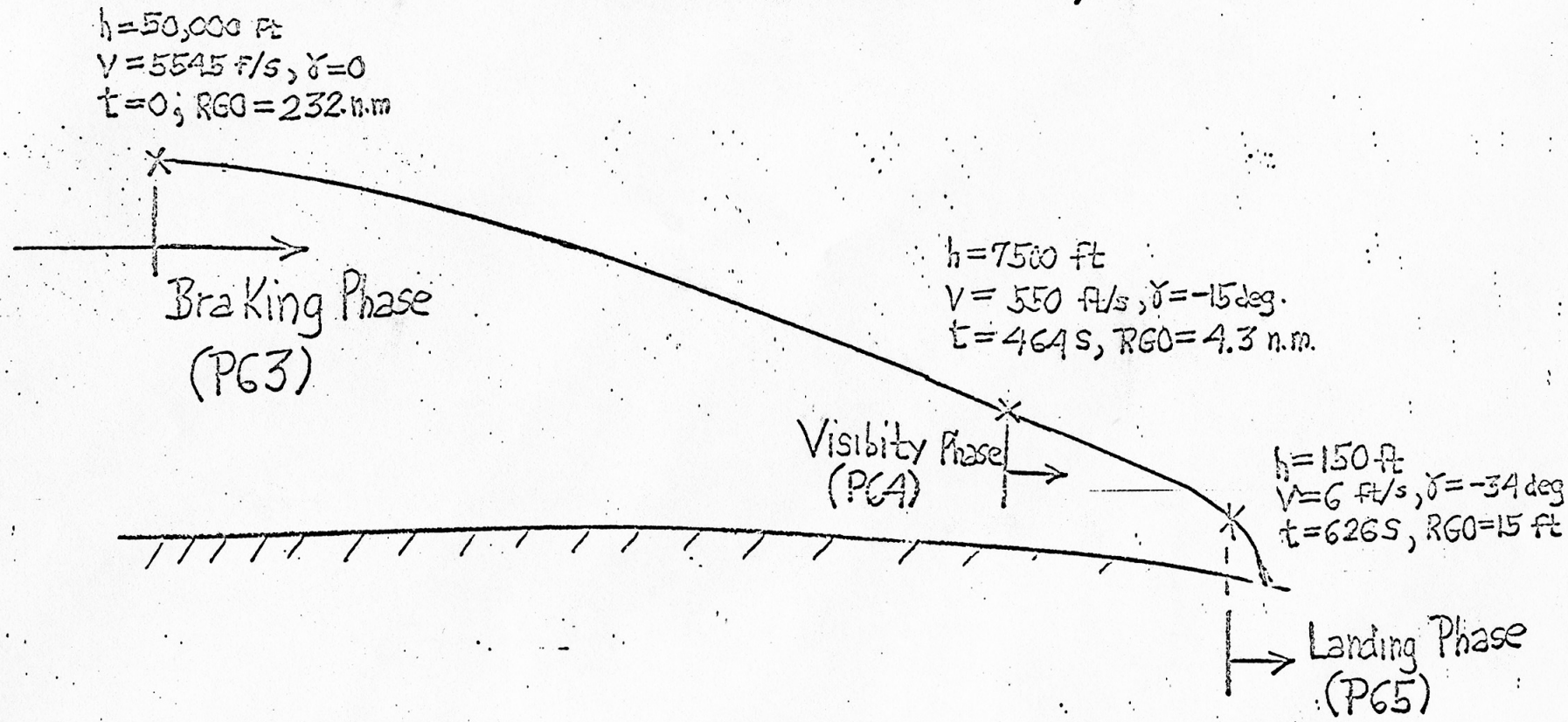
- Safely land vehicle at a selected site on the moon with essentially zero velocity
- Accomplish the above objectives under the following conditions:
  - (1.) DPS propellant utilized in an efficient manner
  - (2.) Landing site visible to astronaut for at least 75 sec.
  - (3.) Limited range of throttle settings over which DPS can be operated
  - (4.) Provide manual site-redesignation capability to astronaut when site is visible
  - (5.) Approach-phase trajectory constraints to permit easy astronaut take-over if desired

Landing Maneuver Phases

Number	Phase Name	LGC Programs	Starting time	Starting altitude	Starting speed
−2	Pre-ignition	P63	>−30 min		
−1	DPS ullage and trim	P63	−33.5 sec		
0	Braking	P63	0	50,000 ft	5545 f/s
1	Visibility	P64	464 sec	7200 ft	516 f/s
2	Final descent	P65, P66, P67	633 sec (P65)	150 ft	6 f/s

P63 -- Braking phase program (cannot reenter from P66 or P67)
P64 -- Approach phase program (cannot reenter from P66 or P67)
P65 -- Landing phase automatic program
P66 -- Landing phase rate-of-descent program
P67 -- Landing phase manual program

Nominal Lunar-Landing Geometry



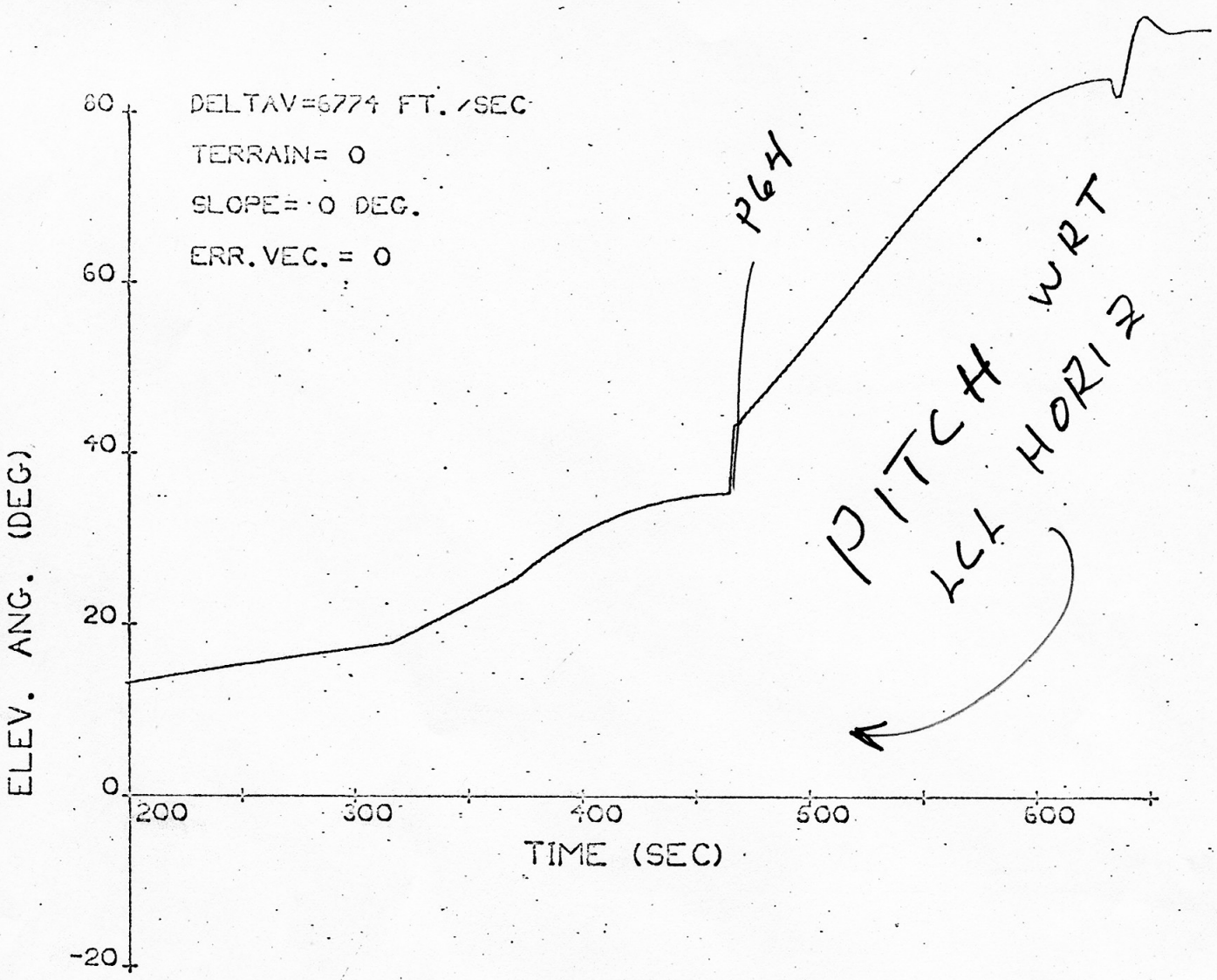
Landing Maneuver Displays

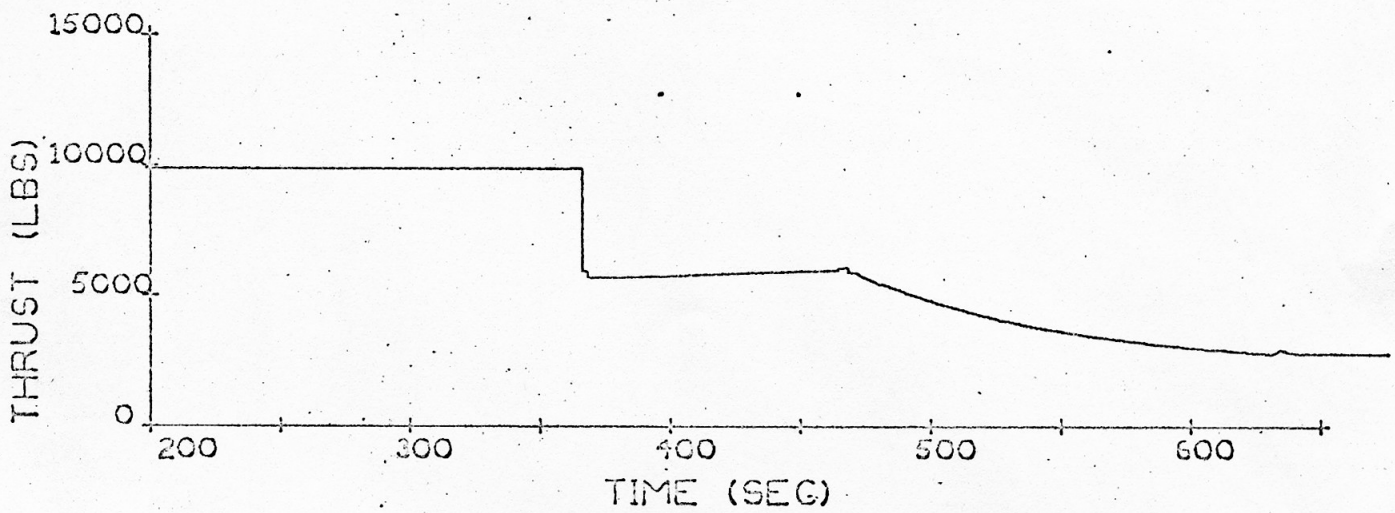
DSKY

Loc.	Preignition	TIG-30	Start of Brak Pr.	Any Time in P63	Visibility Phase	Final Descent
R1	TGO	V_P	V_P	RANGE	TGO/LPD	V_H
R2	TFI	TFI	HDOT	TGO	HDOT	HDOT
R3	CR	ΔV_M	H	DELH	H	H
Call	V06 N61	V06 N62	V06 N63	V16 N68 E	V06 N64	V06 N60

Analog Displays: H, HDOT, V_{HF}, V_{VF}

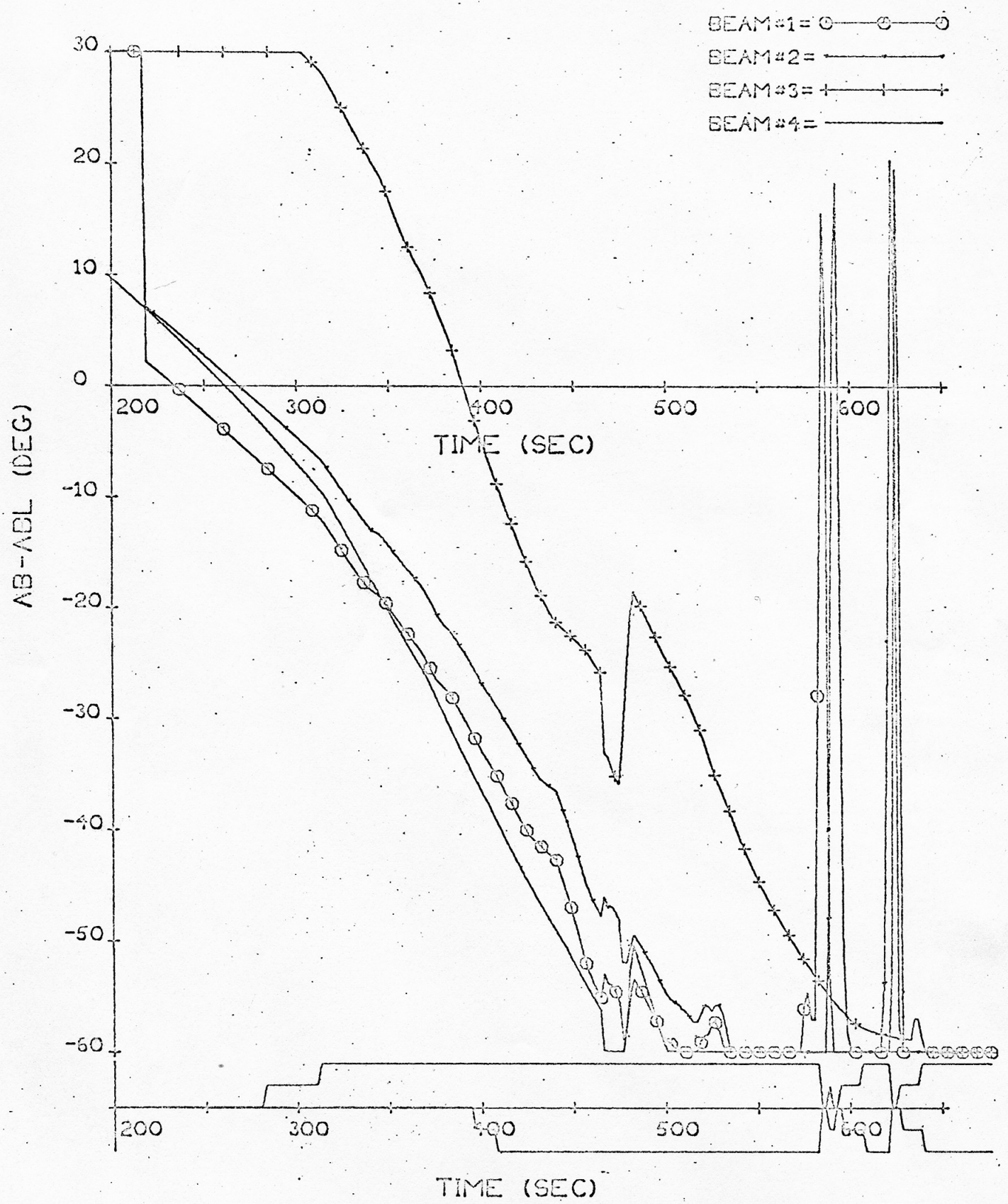
Thrust-Vector Elevation and Magnitude: Nominal





BAK DEG
RUN NO. =313

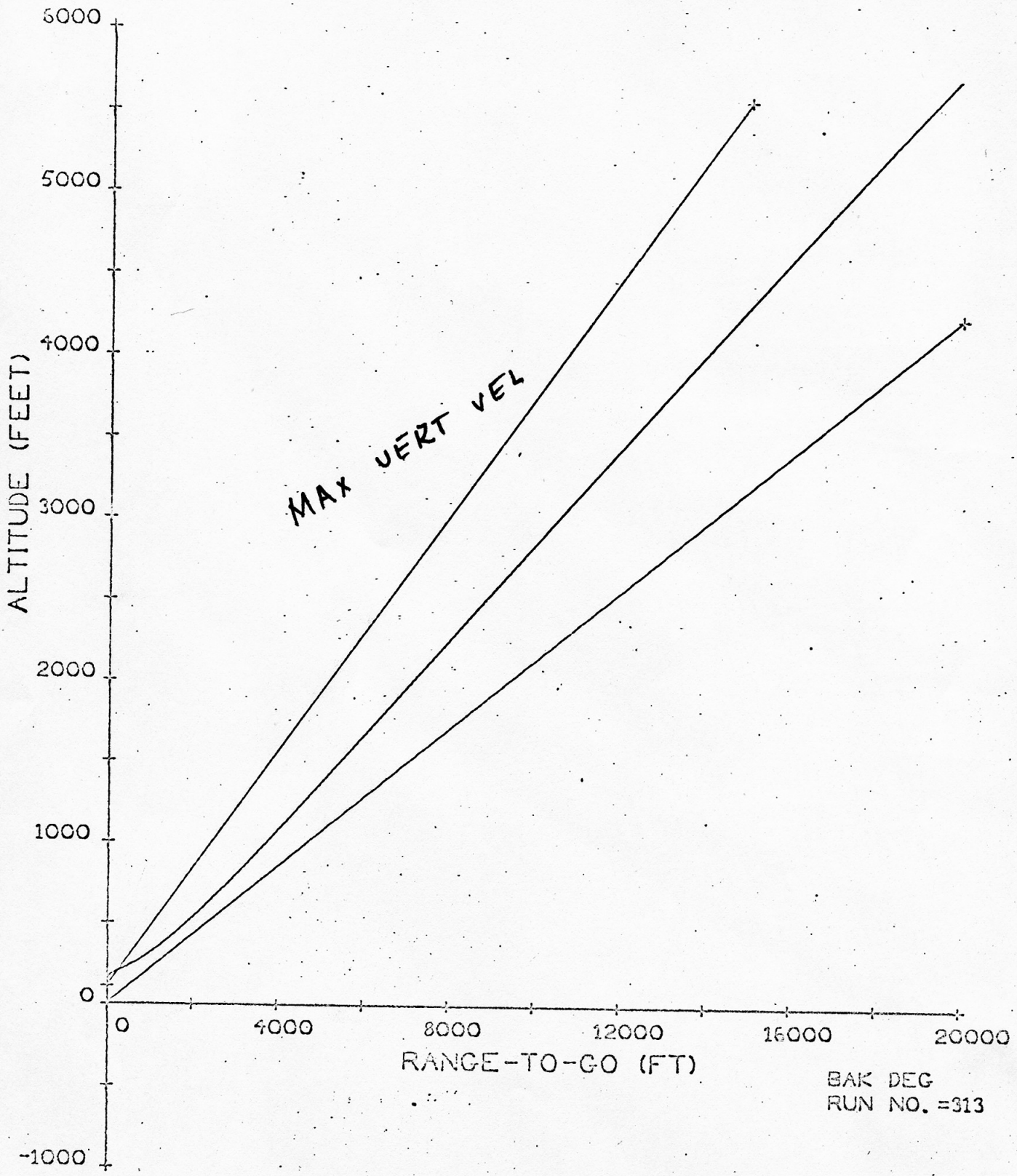
LR Beam Angles w.r.t Dropout Boundaries : Nominal



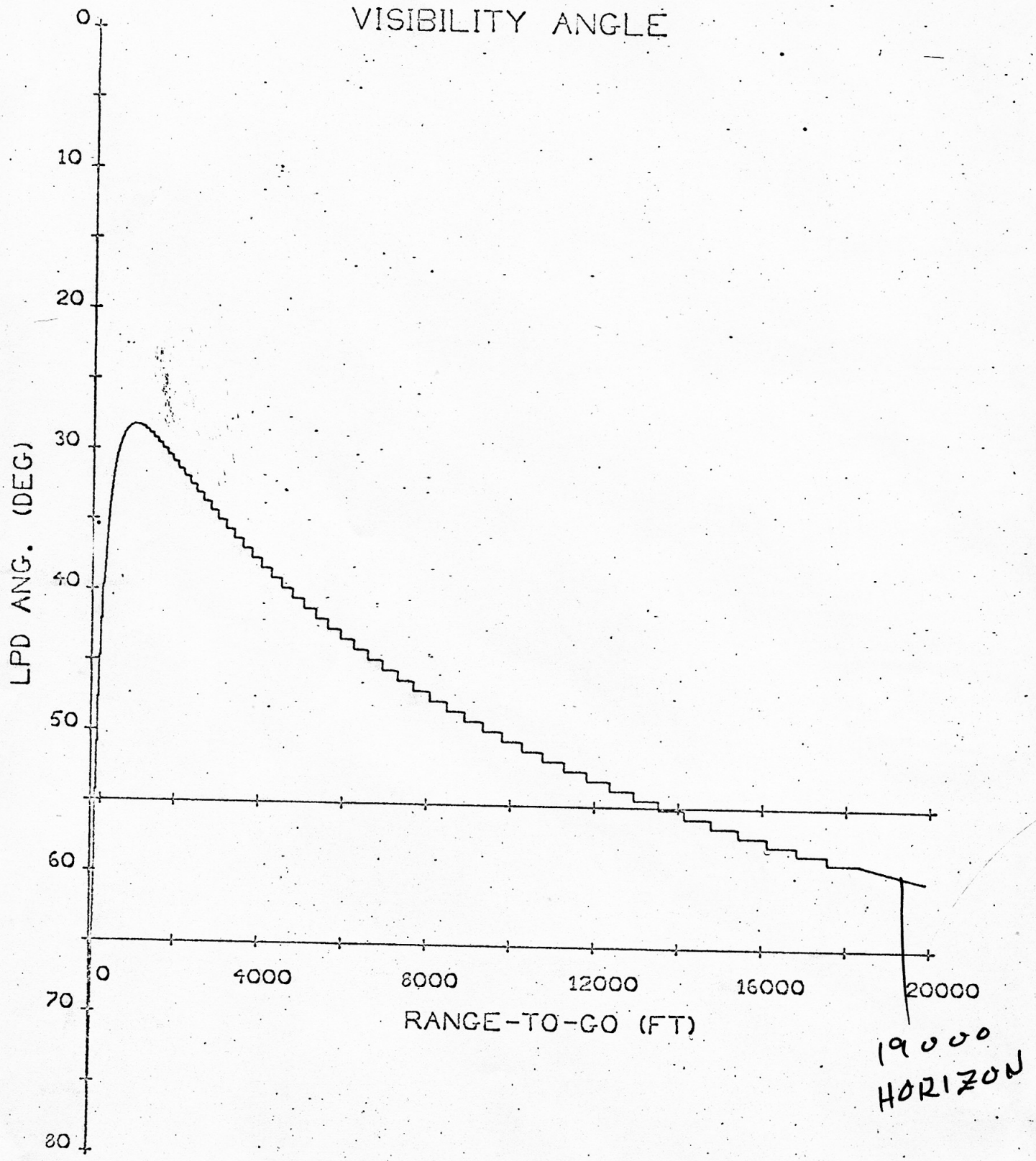
BAK DEG

RUN NO. =313

Altitude Profile for Last 20,000 ft : Nominal

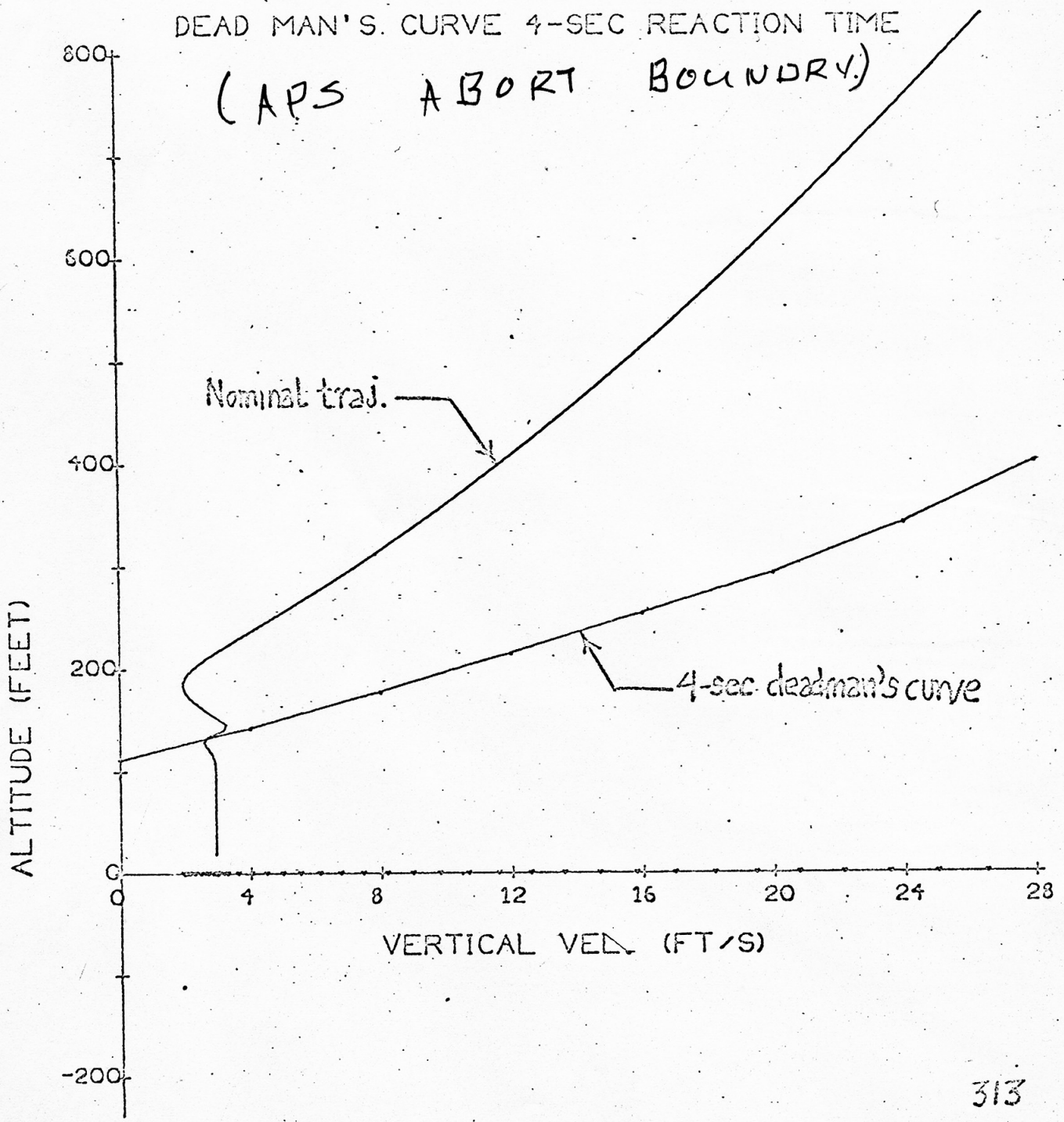


LPD Angle on Nominal Trajectory



BAK DEG
RUN NO. =313

Altitude vs. Vertical Velocity : Nominal



Scope of State-Vector Routine Talk

- Navigation sensor performance characterics --- IMU and LR on nominal trajectory, propagation of initial errors
- Description of routine -- general functions, tests, layout
- Various tests relating to the incorporation of LR data -- flags to set, alarms, DSKY Lights
- Updating relations and weighting functions
- LR acquisition and dropouts on nominal and off-nominal trajectories
- Data reasonableness tests -- possible LockOuts of LR data
- System performance data for simulated automatic landings to sites II-P-6 and/or II-P-2, including terrain profiles, terrain slopes, initial-condition errors, DPS thrust-acceleration variations, LR & IMU errors

Descent State-Vector Routine R-12

Basic Functions:

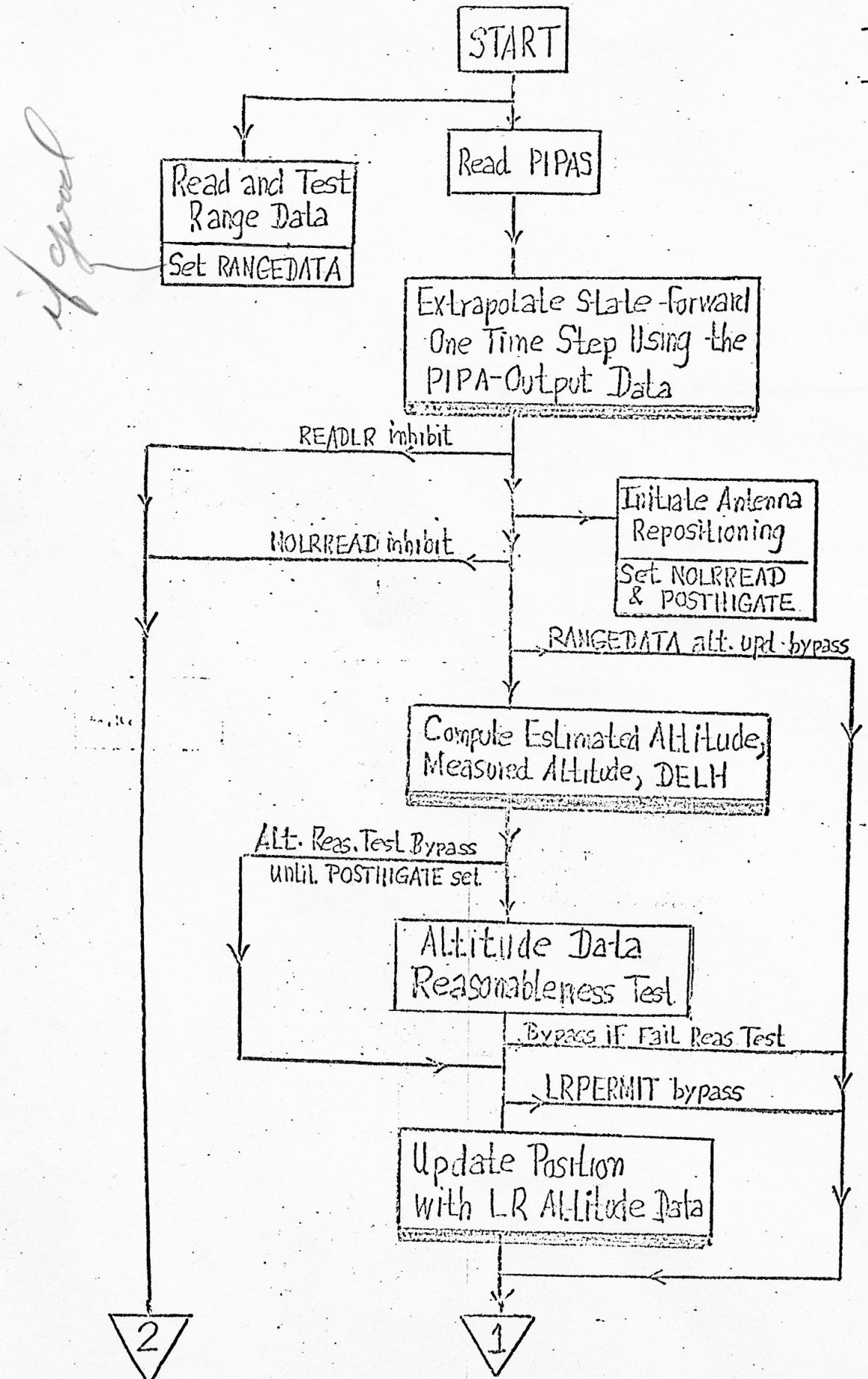
- Extrapolate the LM state estimate ($\underline{r}_p, \underline{v}_p$) forward one time step using the current PIPA output data
- Update the extrapolated position estimate with LR altitude data, provided that certain tests are passed
- Update the extrapolated velocity estimate with LR velocity-component data, provided that certain tests are passed

Primary Inputs: PIPA output data ($\Delta\tilde{\underline{v}}_p$), LR range, LR velocity-component measurements

Primary Outputs: Up-to-date estimates of LM position ($\underline{r}_p$) and velocity ($\underline{v}_p$) in stable-member coordinates

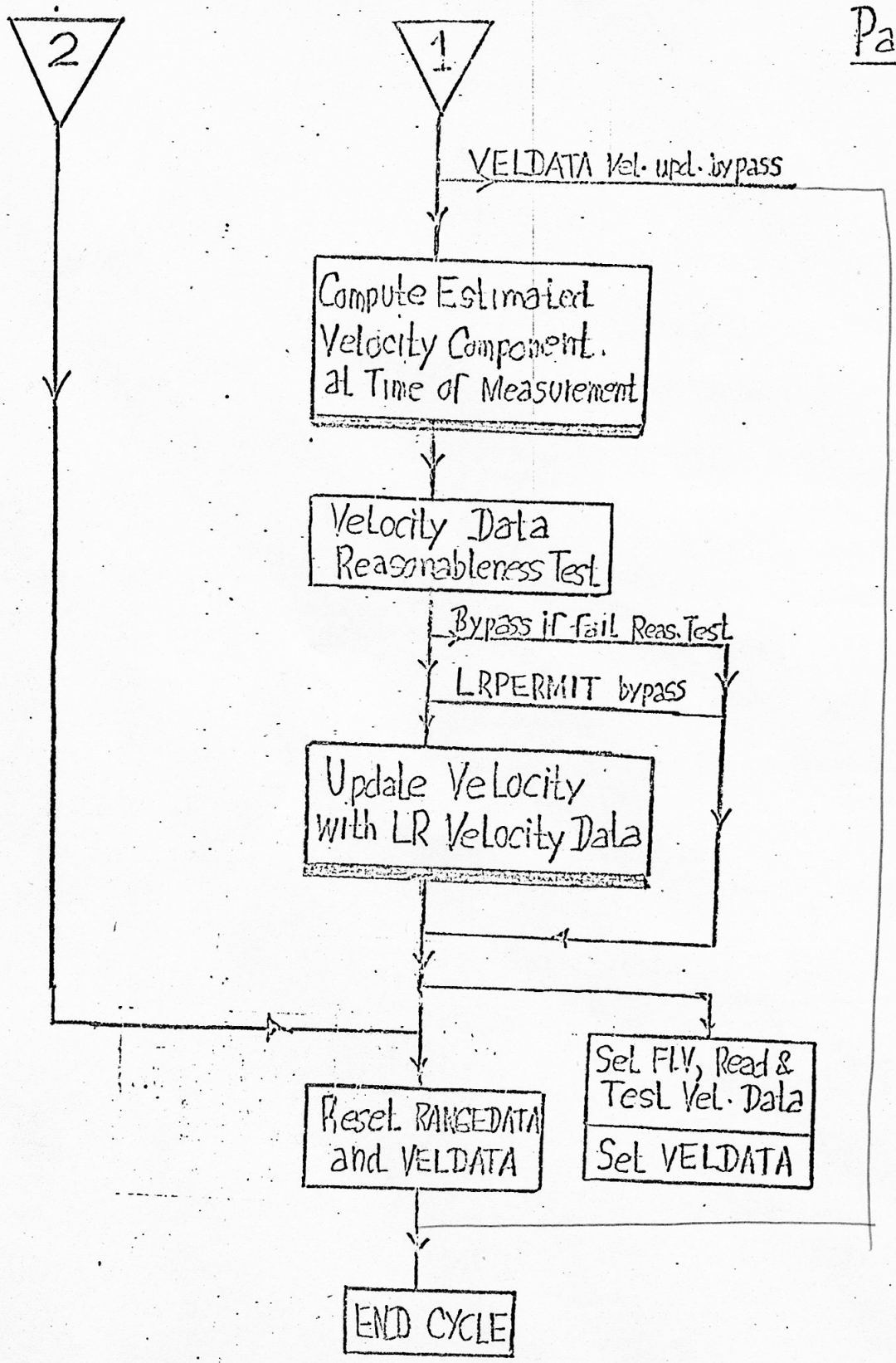
Descent State-Vector Routine R-12

Part 1



Descent State-Vector Routine R-12

Part 2



LR Updating Relations

Altitude:

every 2 sec

$$\boxed{\underline{r}_P = \underline{r}_P + W_H(DELH)\,\underline{u}_{HP}}$$

$$DELH = \tilde{q}^* - q' \text{ ---------- DSKY (DELH)}$$

$$\tilde{q}^* = -\tilde{q}\,(\underline{u}_{RBP} \cdot \underline{u}_{HP})$$

$$q' = r_p - r_{LS} \text{ ---------- DSKY (H)}$$

$$\tilde{q}^*_{LR} = \tilde{q}\cos(15°) \text{ ---------- TAPEMETER (H)}$$

in meter

Superscripts

$\sim$ = raw meas.

$'$ = estimate

$*$ = computed from meas.

Velocity:

x every 6
Y every 6
Z every 4

$$\boxed{\underline{V}_P = \underline{V}_P + W_V(\delta q_u)\,\underline{u}_{AP_u}}$$

$$\delta q_u = \tilde{q}_u - q'_u$$

$$q'_u = \underline{V}'_{P_u} - \underline{\omega}_P \times \underline{r}_P$$

X Y Z X

r_2 r_1 z' z_1

Landing Radar Weighting Functions

Altitude:

Selection Criterion	Weighting Function
$h' > LRHMAX$	$W = 0$
$h' \leq LRHMAX$	$W = LRWH\left(1 - \frac{h'}{LRHMAX}\right)$

Present Erasable Values	
LRHMAX	50,000 Ft
LRWH	.35

Velocity:

Programs	Selection Criterion	Weighting Function
P63 P64	$V' > LRVMAX$	$W = 0$
	$LRVMAX \geq V' > LRVF$	$W = C\left(1 - \frac{V'}{LRVMAX}\right)$ $C = LRWVX, Y, Z$
	$V' \leq LRVF$	$W = C$ $C = LRWVFX, Y, Z$
P65, P66 P67		$W = LRWVFF$

Present Erasable Values	
LRVMAX	2000 Ft/s
LRVF	200 Ft/s
LRWVX	.3
LRWVY	.3
LRWVZ	.3
LRWVFX	.2
LRWVFY	.2
LRWVFZ	.2
LRWVFF	.1

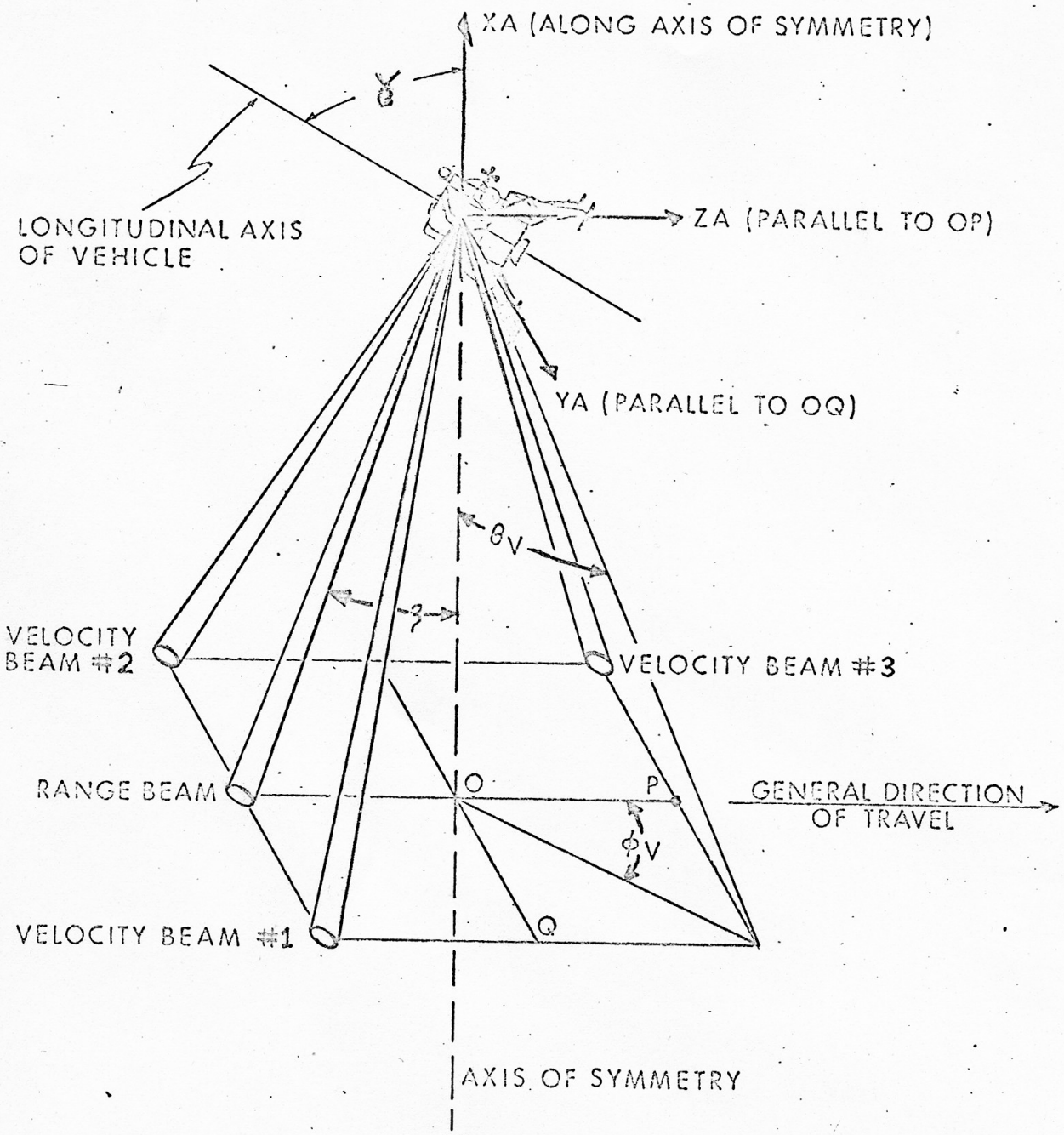
Tests Relating to Incorporation of LR Data

Test or Flag to set	Purpose	How Set
LRPERMIT	Inhibit or allow LR updatings	Astronaut -- use of V 57 Permit / V 58 Inhibit
LRBYPASS	Inhibit LR updatings	LGC during P12, P70, P71
READLR	Permits LR data to be read	LGC -- $\dot{h}' <$ HUP (50,000 FL)
READVEL	Permits LR velocity data to be read	LGC -- $V' <$ VUP (2000 F/s)
NOLRREAD	Inhibits LR updatings and the reading of LR data	LGC -- set when antenna repositioning is started, reset when Position-2 discrete obtained
POSTHIGATE	Cause computer to check for Position-2 Discr.	LGC -- $t_{GO} < t_{SW}$ & $U_{XBXP} > a_{SW}$
FLAUTOX	Inhibits X-axis over-ride option	LGC -- $\dot{h}' <$ 30,000 ft
RANGEDATA (data good)	Inhibits LR altitude updatings if not set	LGC -- Range data-good discrete on two consecutive measurements (3)
VELDATA	Inhibits LR velocity updatings if not set	LGC -- Velocity data-good discretes on two consecutive measurements (3)

FLV

Lights and Alarms Relating to Operation of LR

Problem	Indication
No LR Range Data-Good Discrete	DSKY Altitude-Fail Light ON Steady (range data-good discrete turns off if range>2481')
No LR Velocity Data-Good Discrete	DSKY Velocity-Fail Light ON Steady (vel. data-good discretes turns off)
No Range Low-Scale Discrete after LR Range < 2481 feet	DSKY Altitude-Fail Light ON Steady (range low-scale discrete turns off)
No Position-2 Discrete after 22 sec from time LR Position Command Discrete is issued to the LR.	Program Alarm
No Position-1 Discrete before LR Pos. Command Discrete is issued to the LR	Program Alarm
Two of Last four altitude meas. failed reasonableness test	Flash LR Altitude Fail Light (will not flash if test passed)
Two of last four velocity meas failed reasonableness test	Flash LR Velocity Fail Light (will not Flash if test passed)



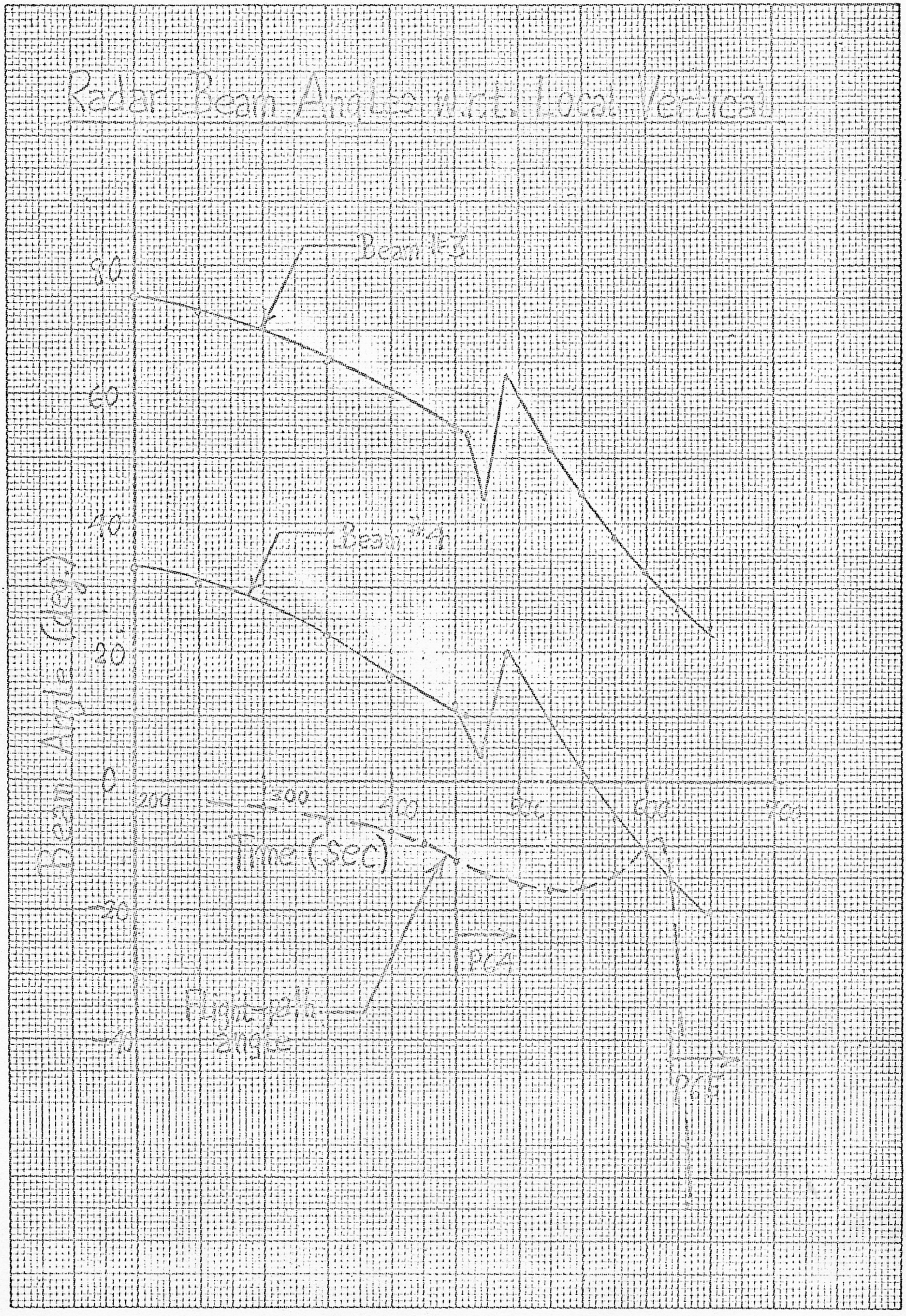
$\zeta = 20.4^\circ$

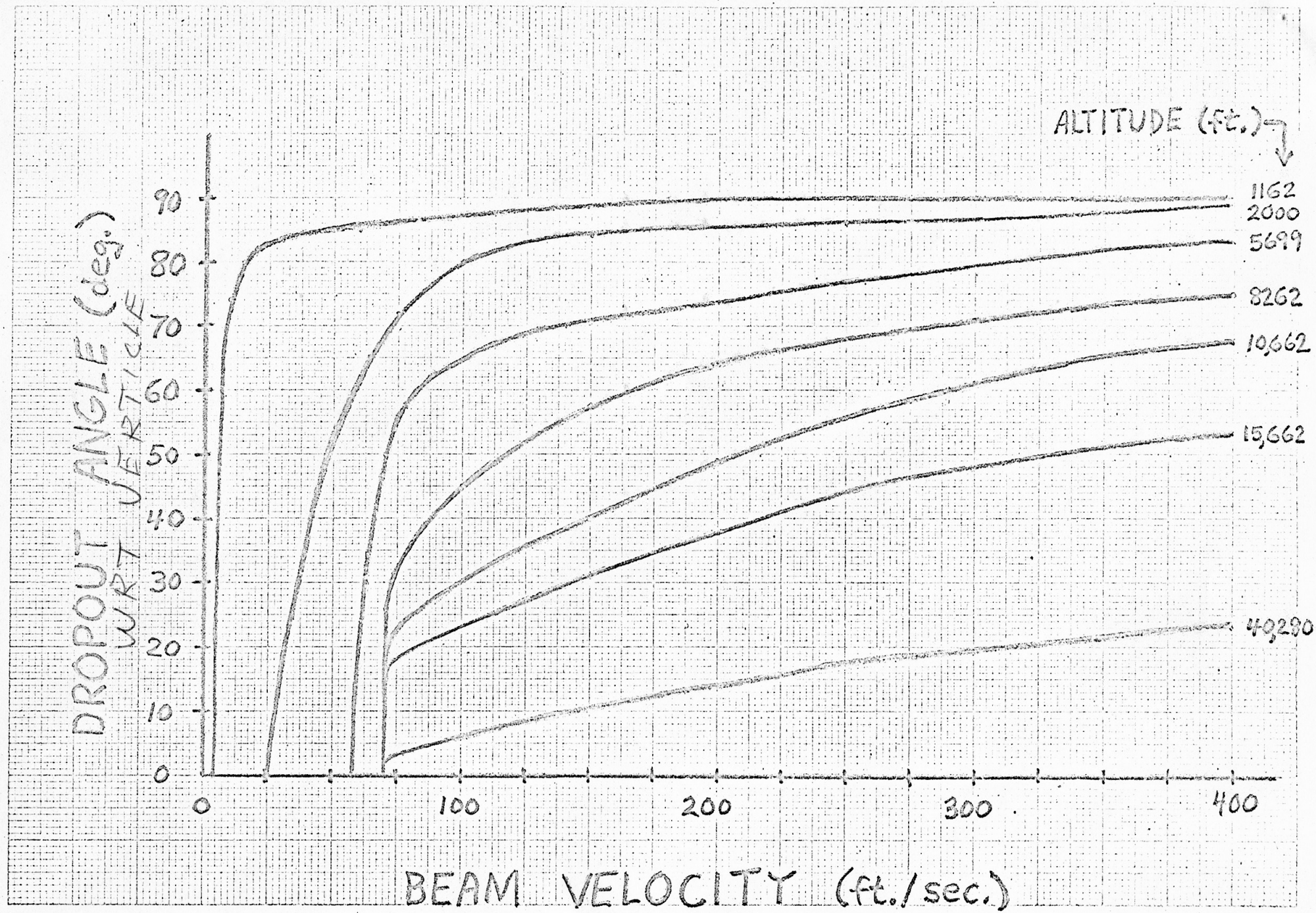
$\theta_v = 24.6^\circ$

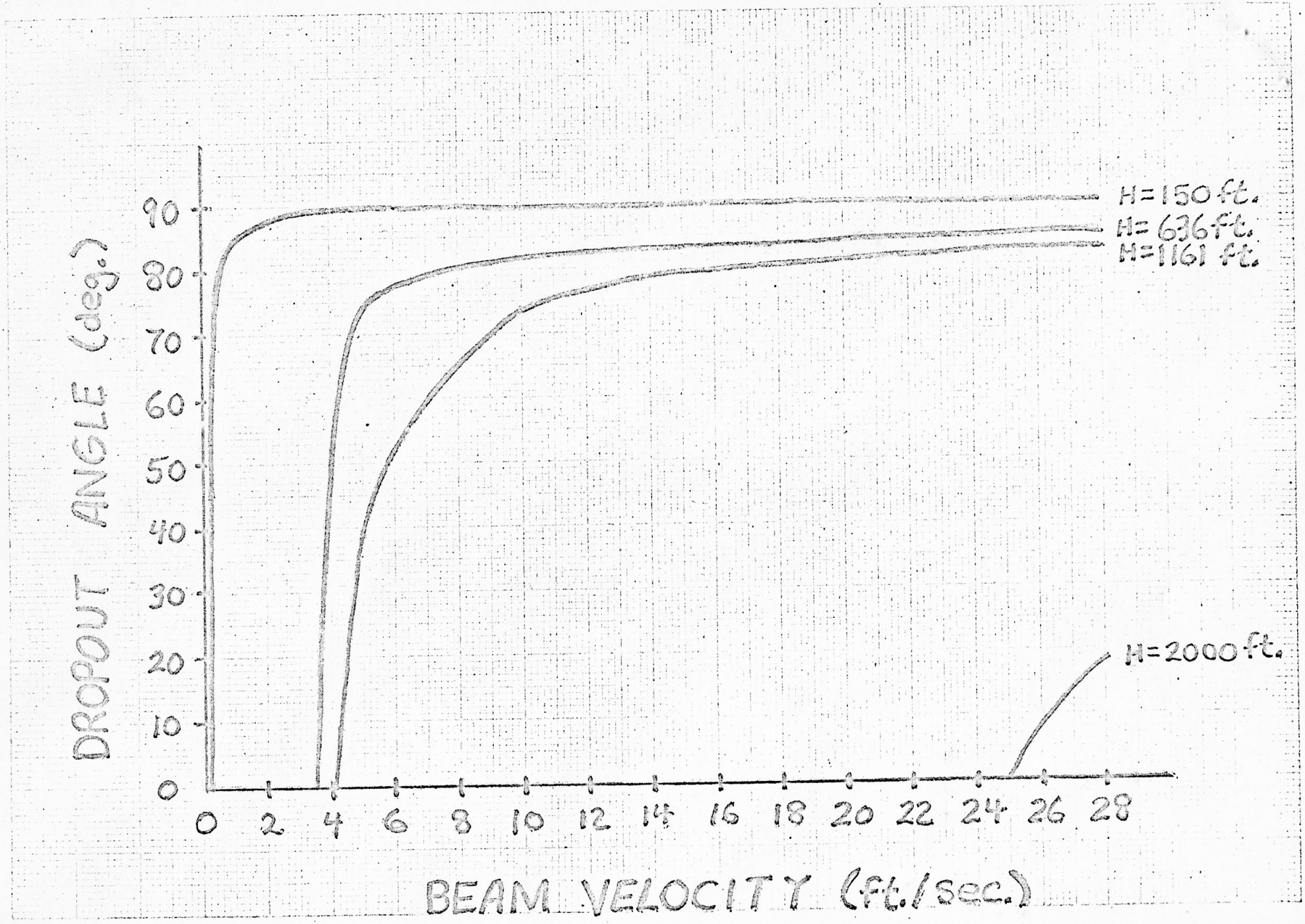
$\phi_v = 35.6^\circ$

$$\gamma = \begin{cases} 24.0^\circ \text{ ; POSITION ONE} \\ 0.0^\circ \text{ ; POSITION TWO} \end{cases}$$

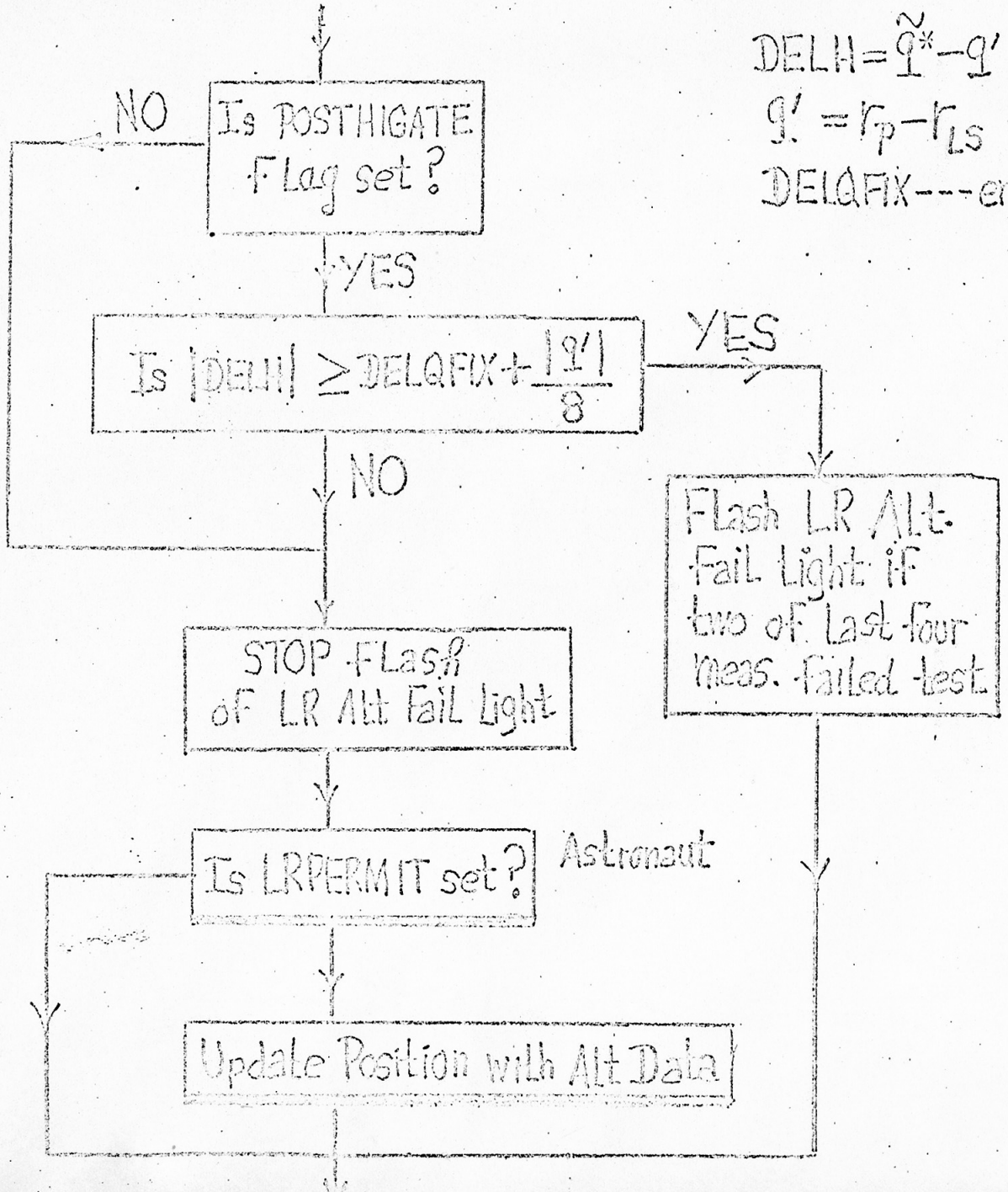
LANDING RADAR GEOMETRY




ALTITUDE (ft.)
1162
2000
5699
8262
10,662
15,662
40,290
DROPOUT ANGLE (deg.) WRT VERTICAL
90
80
70
60
50
40
30
20
10
0
0
100
200
300
400
BEAM VELOCITY (ft./sec.)


DROPOUT ANGLE (deg.)
90
80
70
60
50
40
30
20
10
0
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28
BEAM VELOCITY (ft./sec.)
H=150 ft.
H=636 ft.
H=1161 ft.
H=2000 ft.

Altitude Data Reasonableness Test

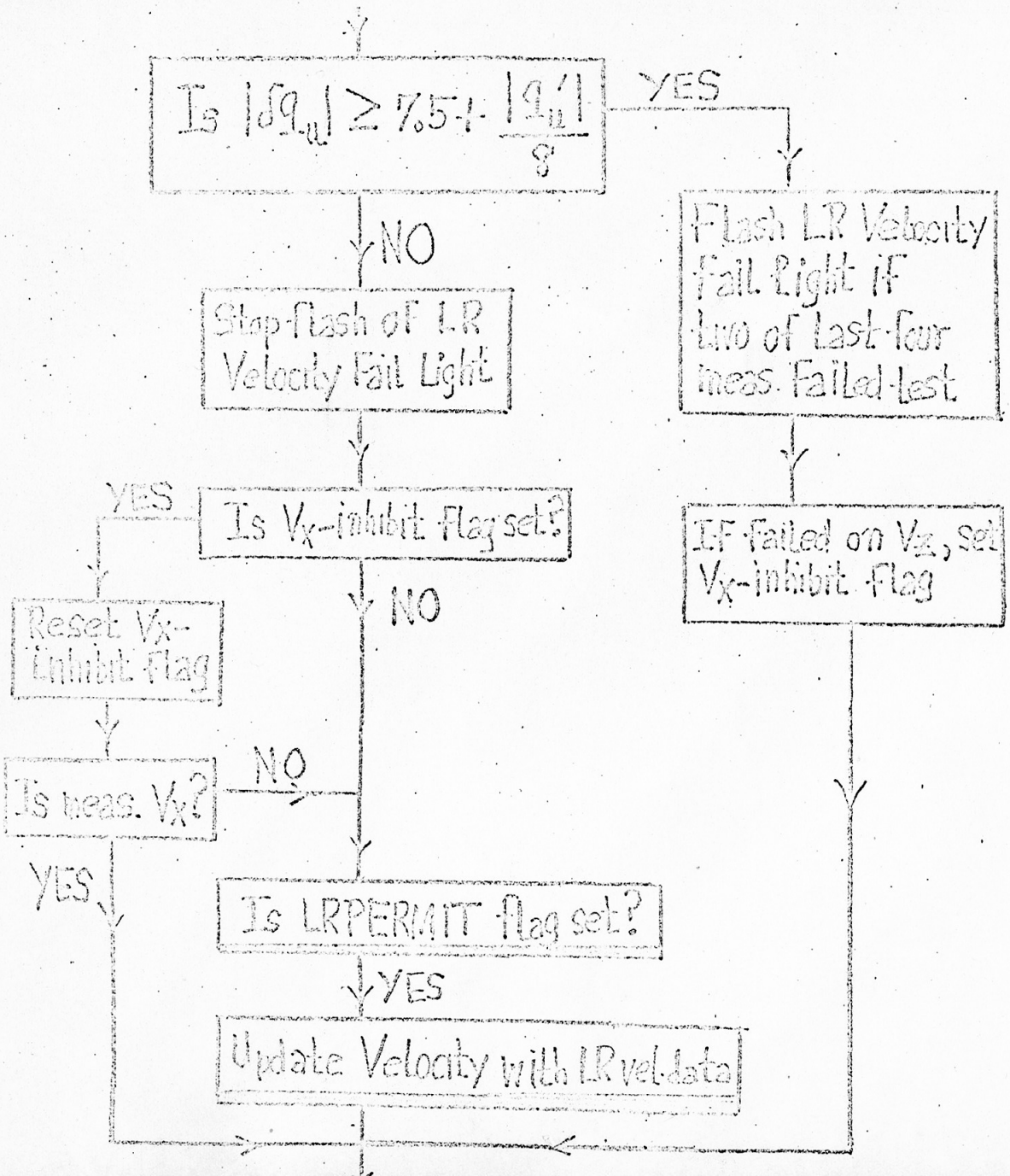


DELH = $\tilde{q}^*$ − q' ---DSKY

q' = $r_p - r_{LS}$

DELQFIX---erasable. (100 Ft)

Velocity Data Reasonableness Test



$$\delta q_u = \tilde{q}_u - q'_u$$

$$q'_u = (V'_u - \omega_p \times r_p) \cdot u_{AP_u}$$

Superscripts

$\sim$ = measured

$'$ = estimated

Subscripts

u = meas. time

P = platform axis

A = antenna axis

X, Y, Z = vel. components along ant. axes

Landing Simulation Assumptions

Initial-Condition Est. Errors: #1191.1

	Position (Ft)	Vel. (F/s)
X	1906	6.8
Y	4400	8.1
Z	−6287	−4.2

(IMU coord. of LS

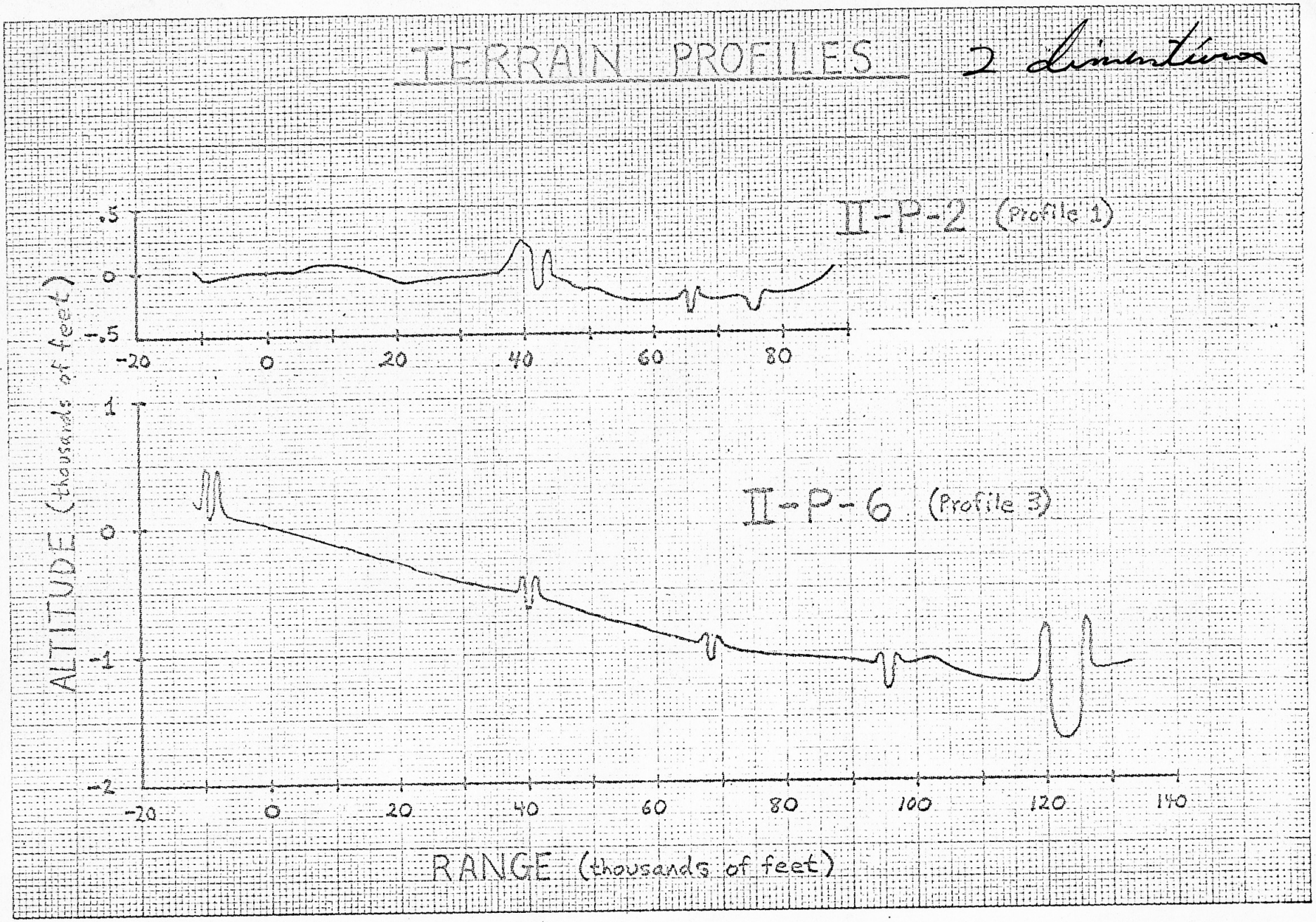
Terrains: II-P-6, Profile 3
II-P-2 Profile 1

Slopes: ±1 deg to maximum of 5000 feet

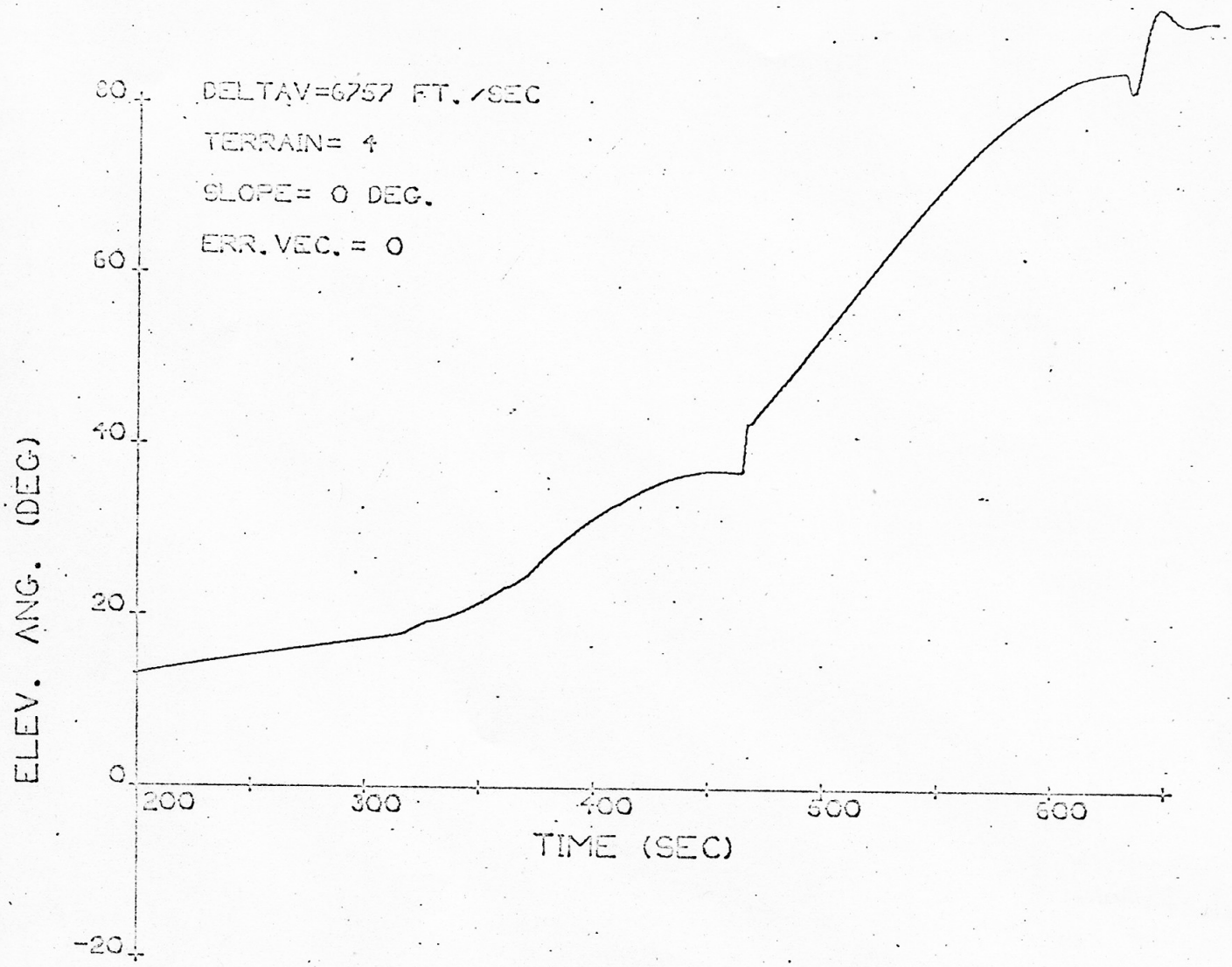
Thrust Acc. Vars.: +1%
−2.5%

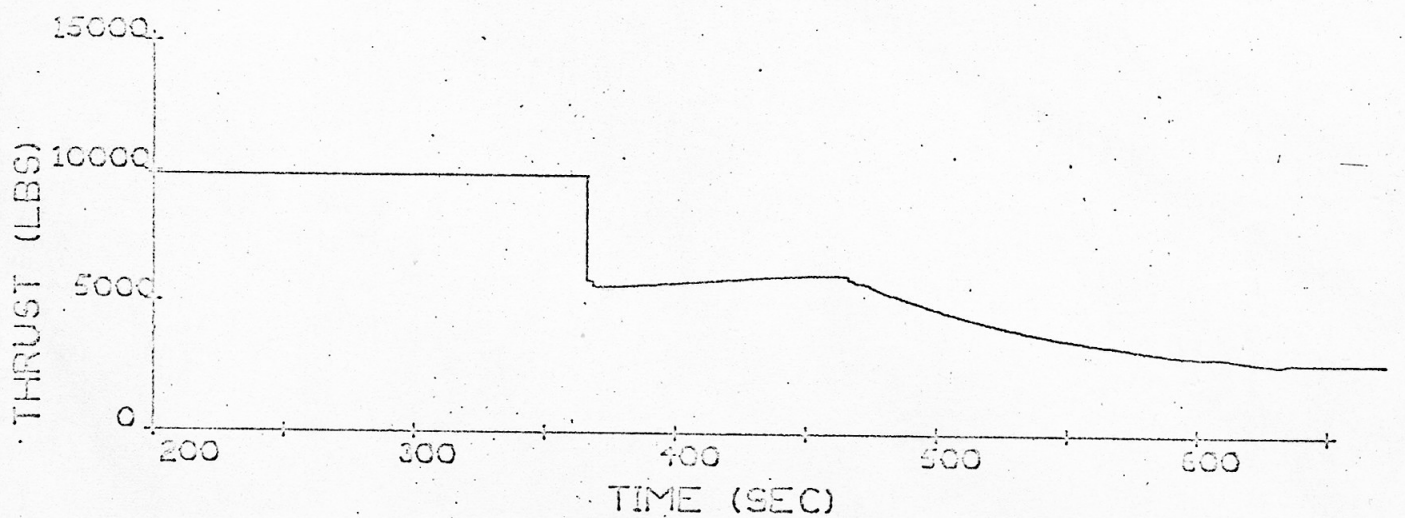
TERRAIN PROFILES

2 diagrams

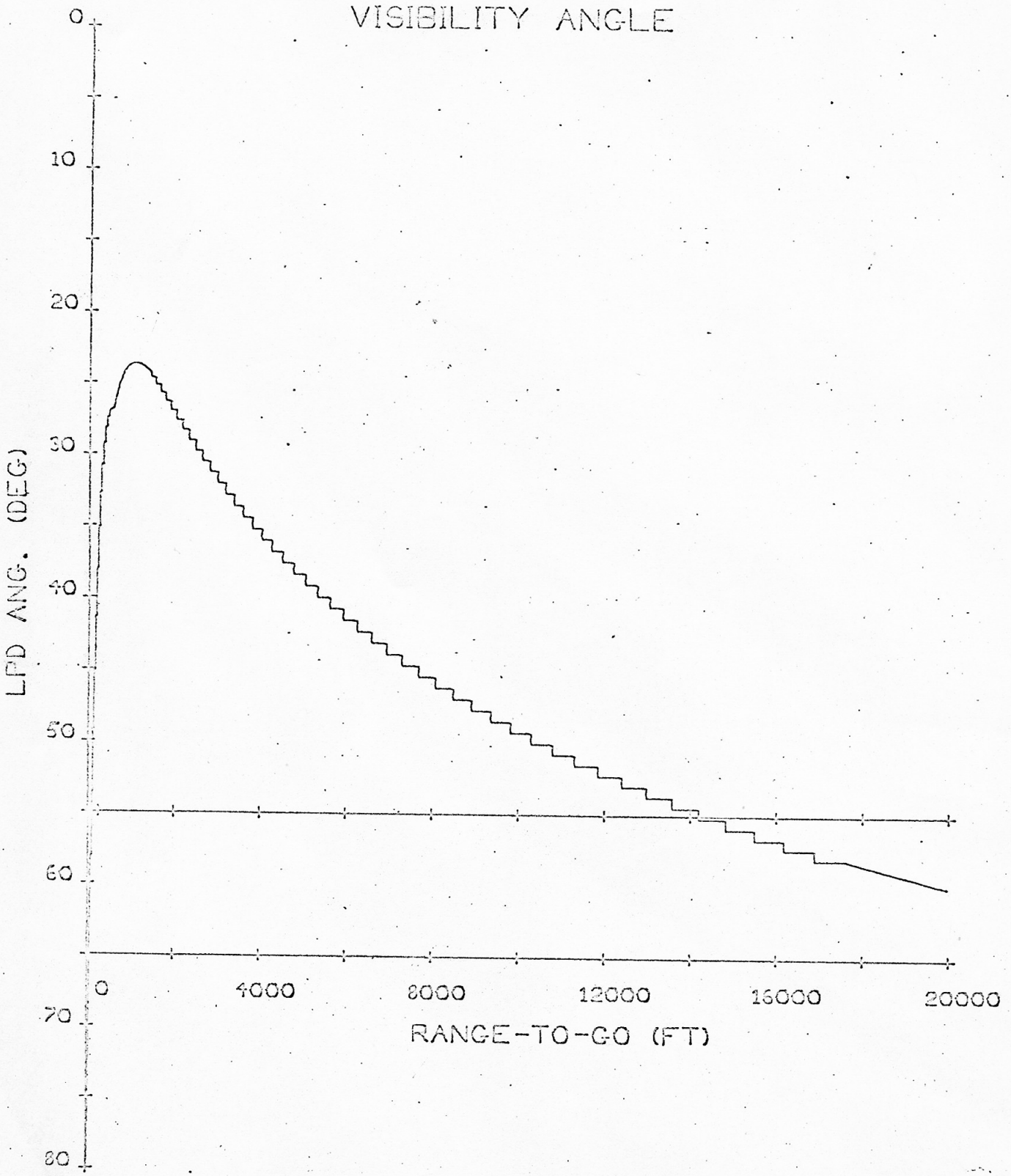


IT Graph

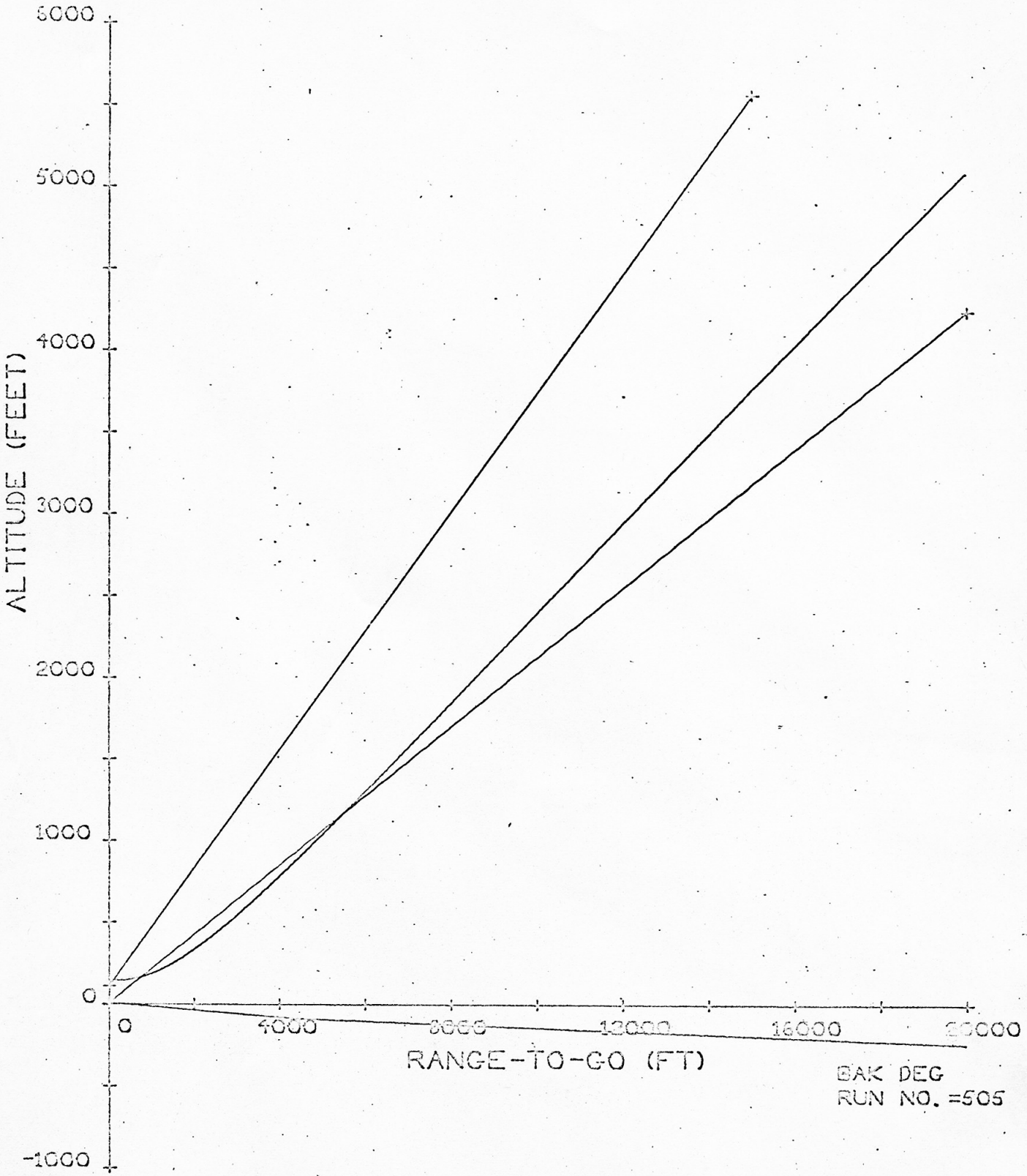




BAK DEG
RUN NO. =505

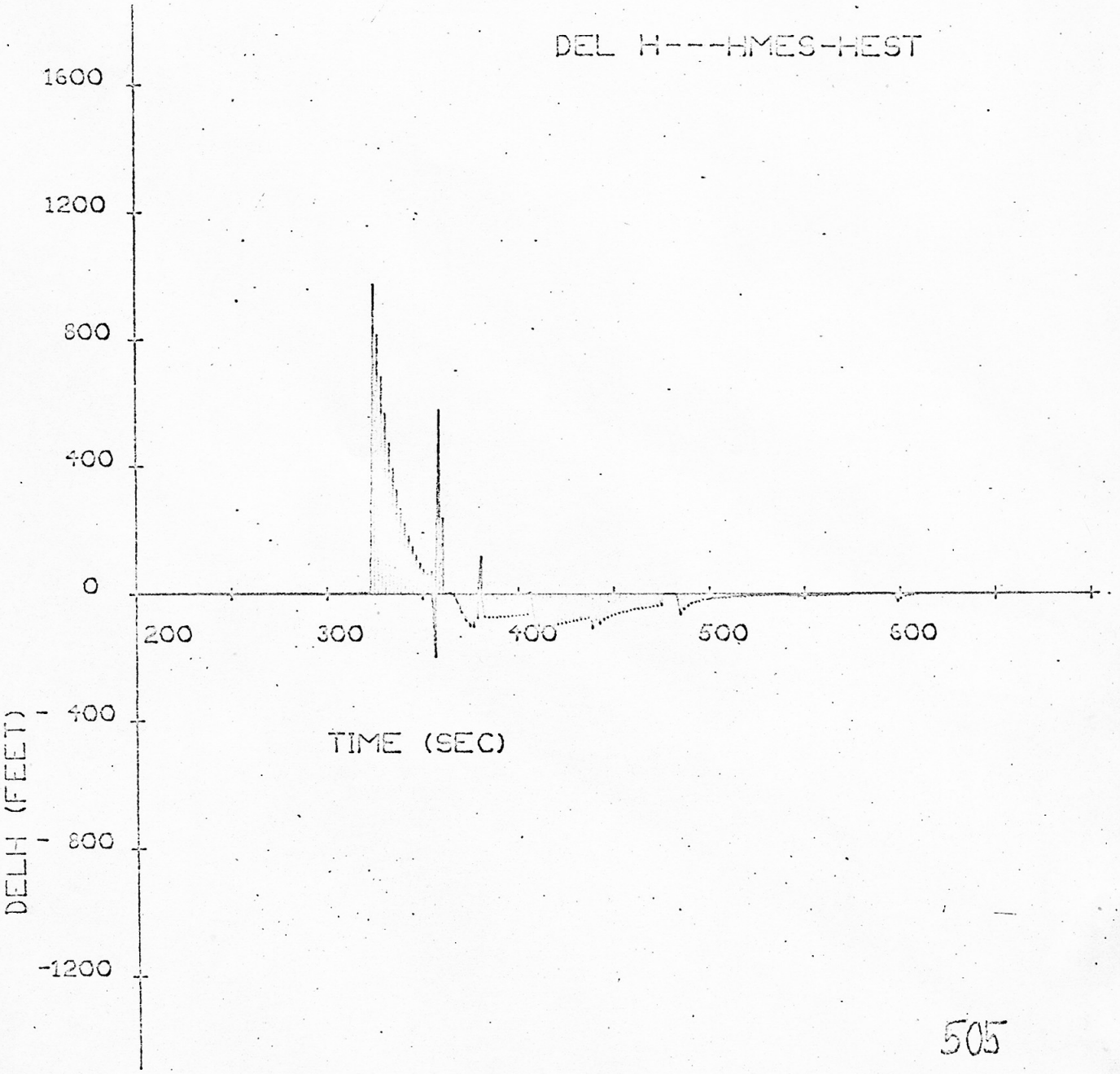


BAK DEC
RUN NO. =505

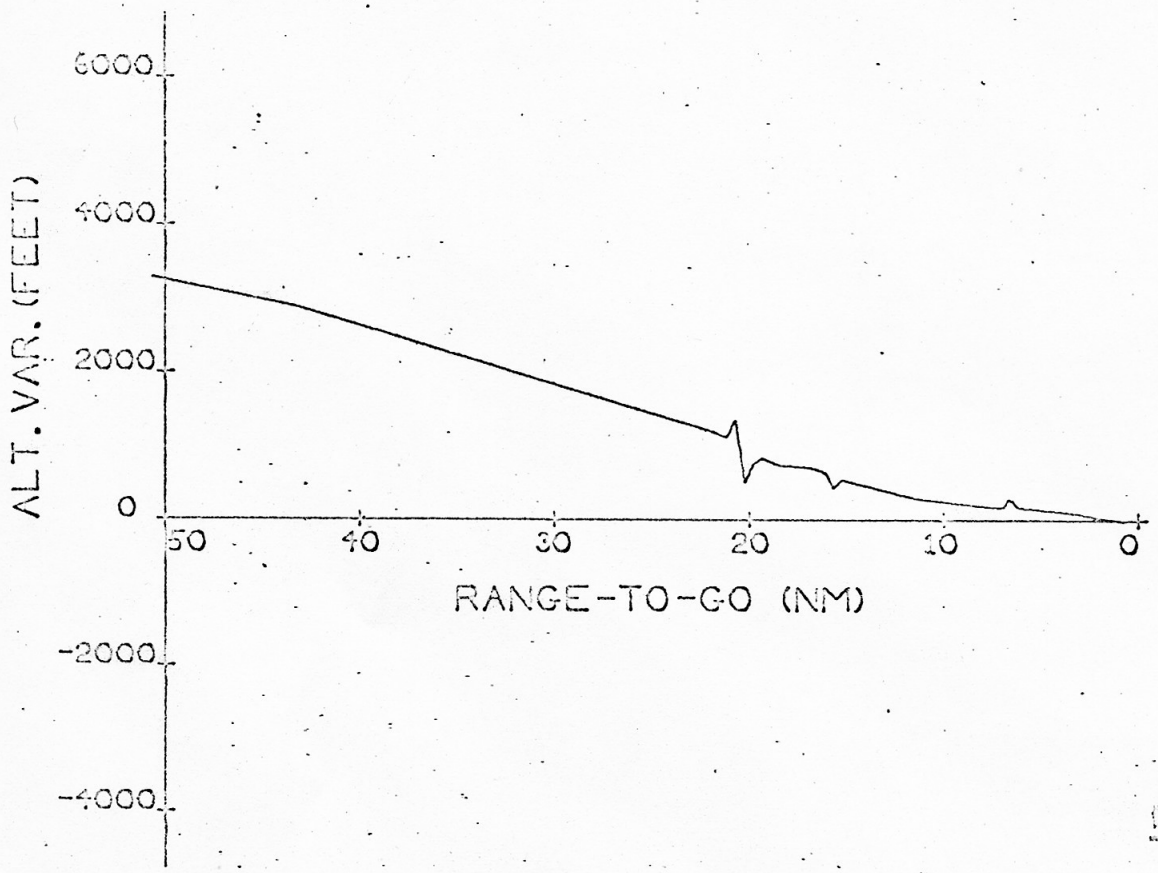

6000
5000
4000
3000
2000
1000
0
-1000
ALTITUDE (FEET)
0
4000
8000
12000
16000
20000
RANGE-TO-GO (FT)
BAK DEG
RUN NO. =505

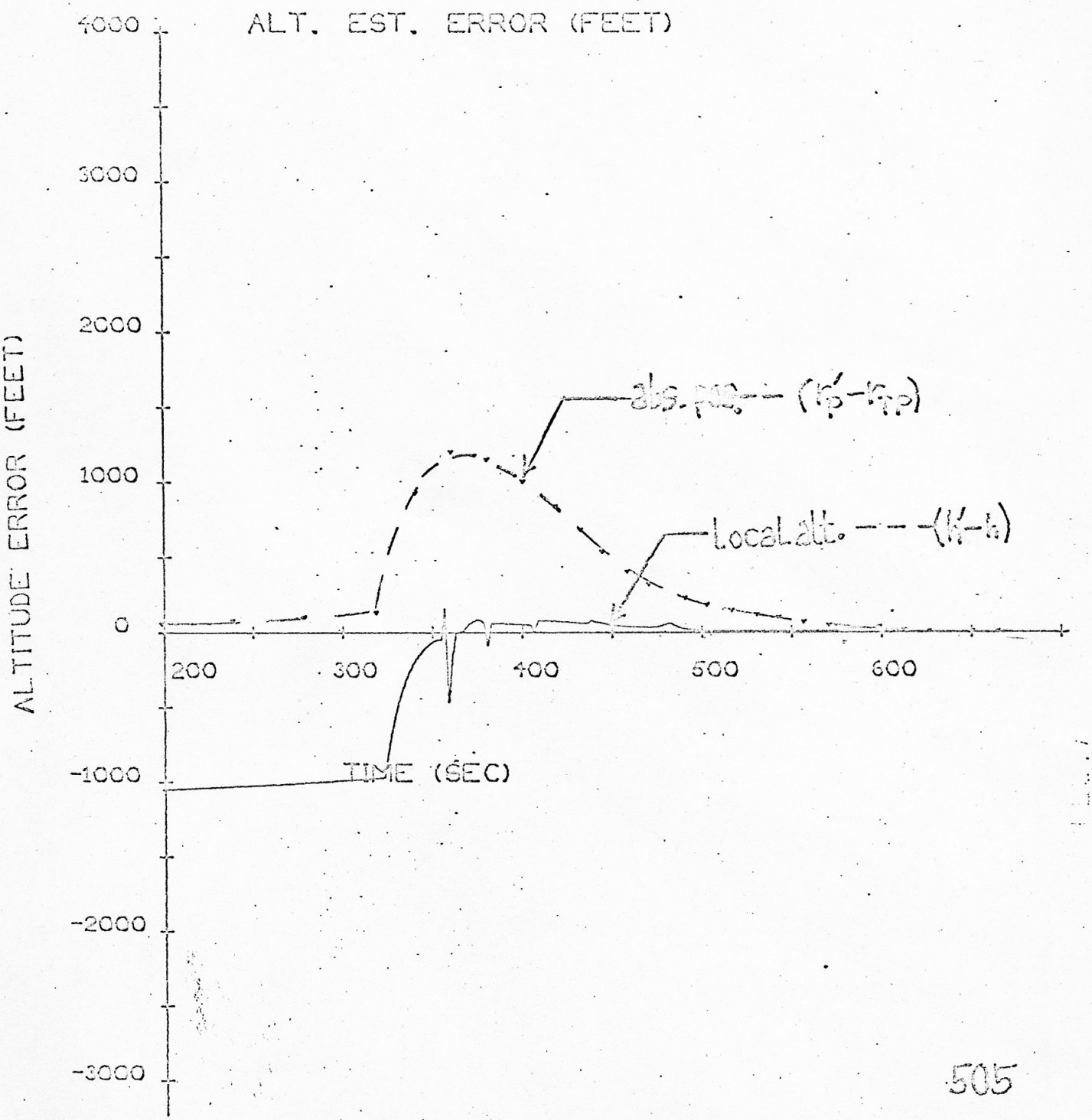
DELH for Error-Free Case I-P-6 Profile 3

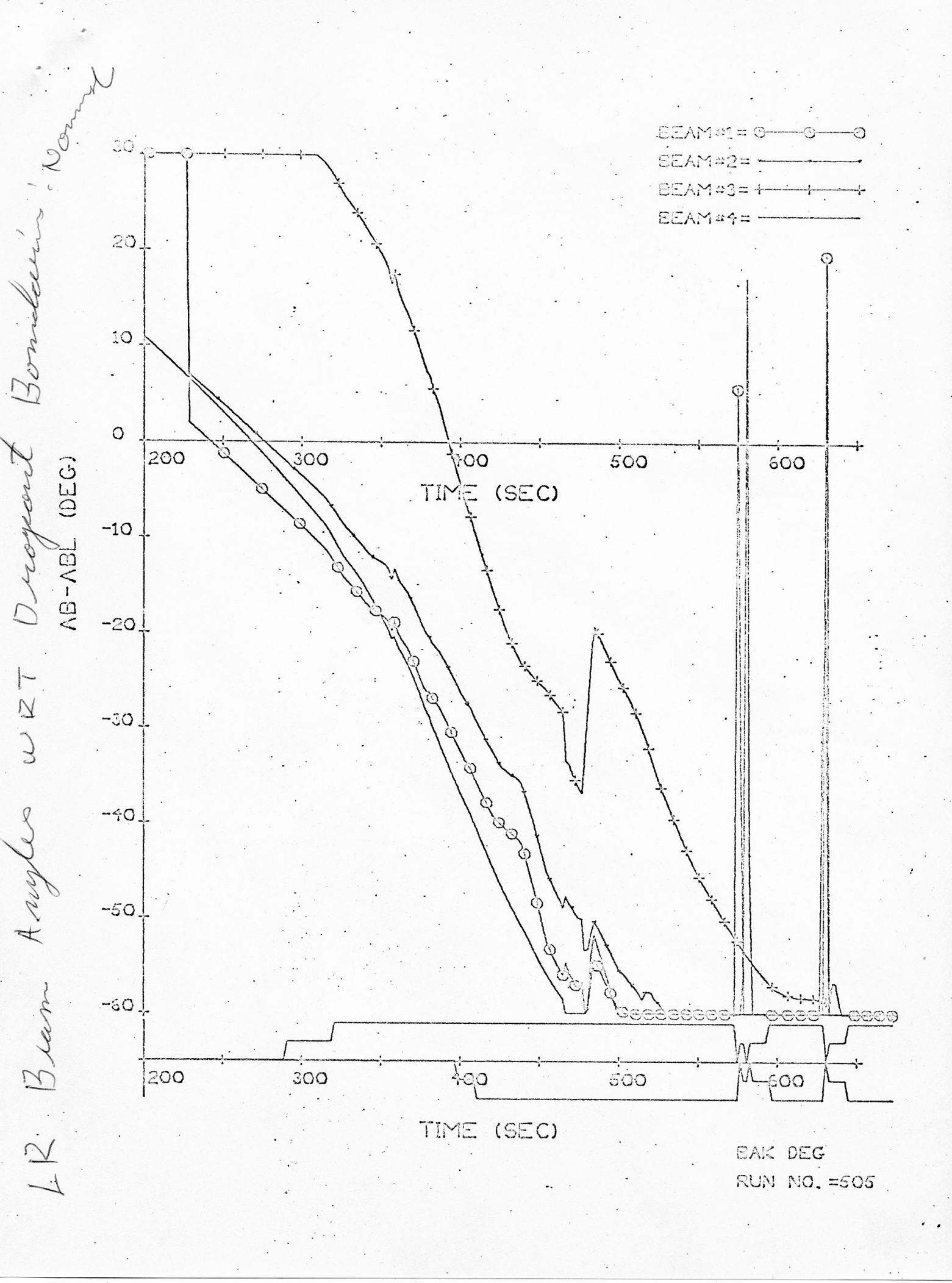
No Slope



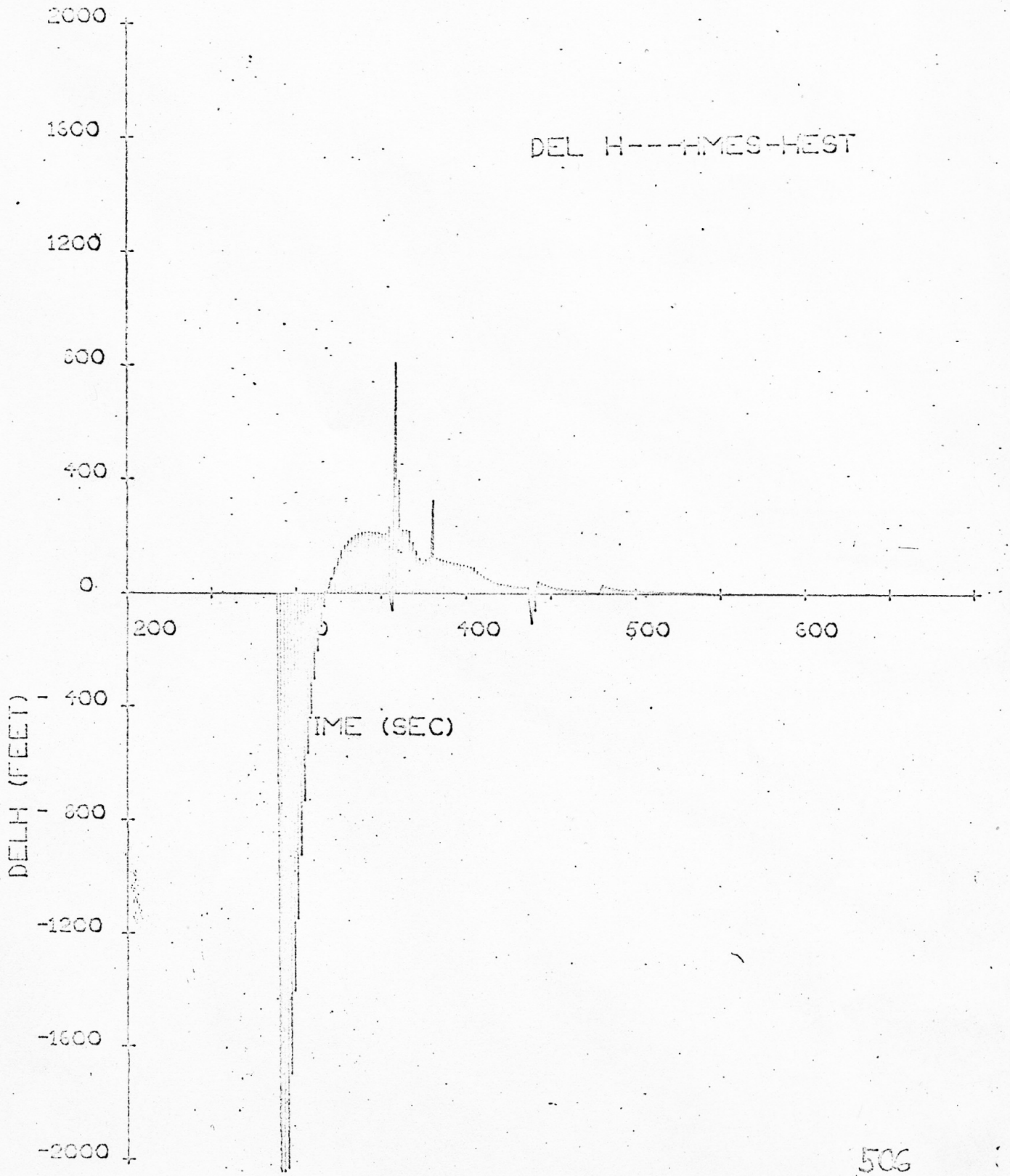
Terrain II-P-6, Profile 3, 1-deg Slope



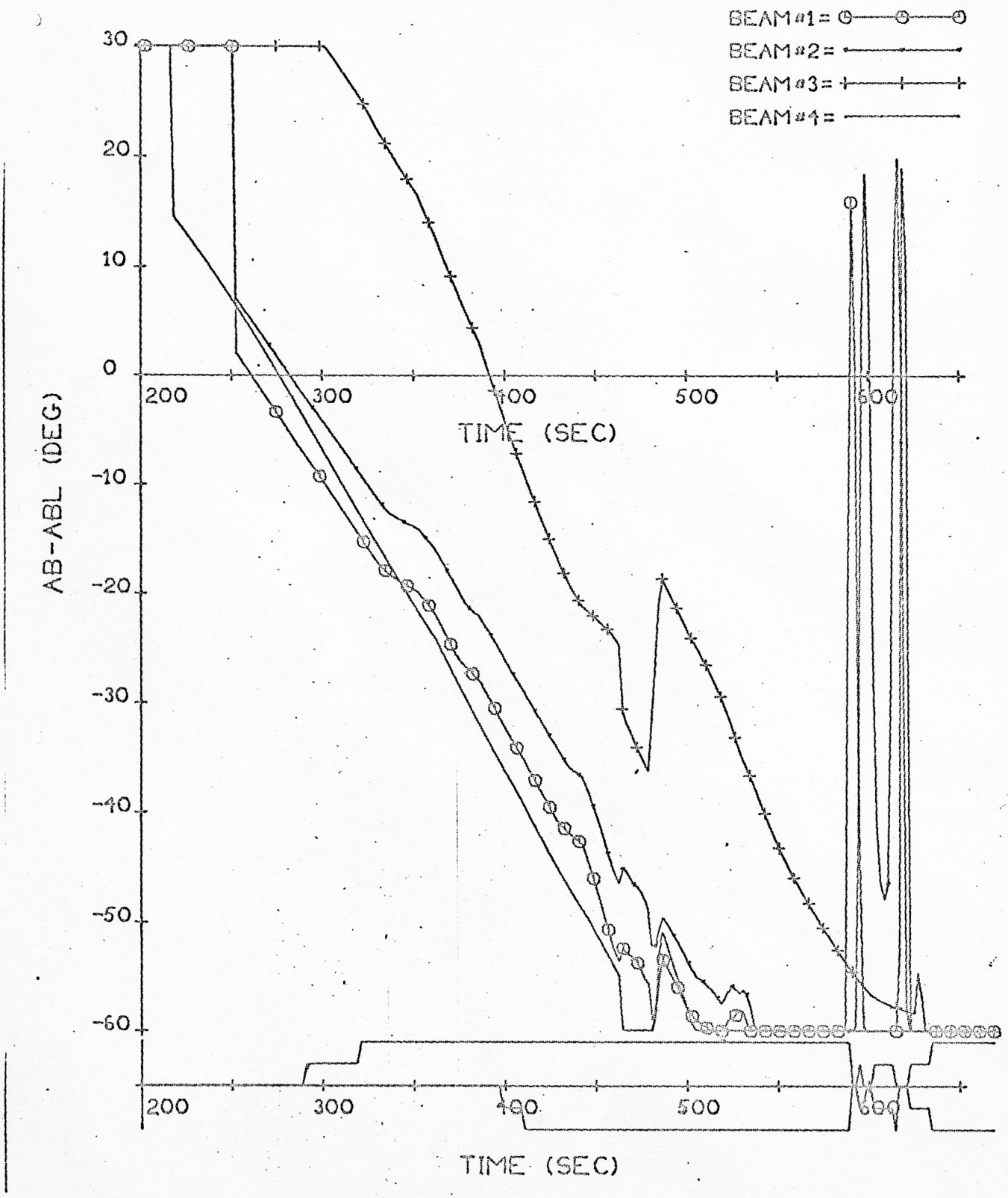

ALT. EST. ERROR (FEET)
4000
3000
2000
1000
0
-1000
-2000
-3000
ALTITUDE ERROR (FEET)
200
300
400
500
600
TIME (SEC)
Abs. Alt. — — (h'p-h'tp)
Local Alt. — — (h'-h)

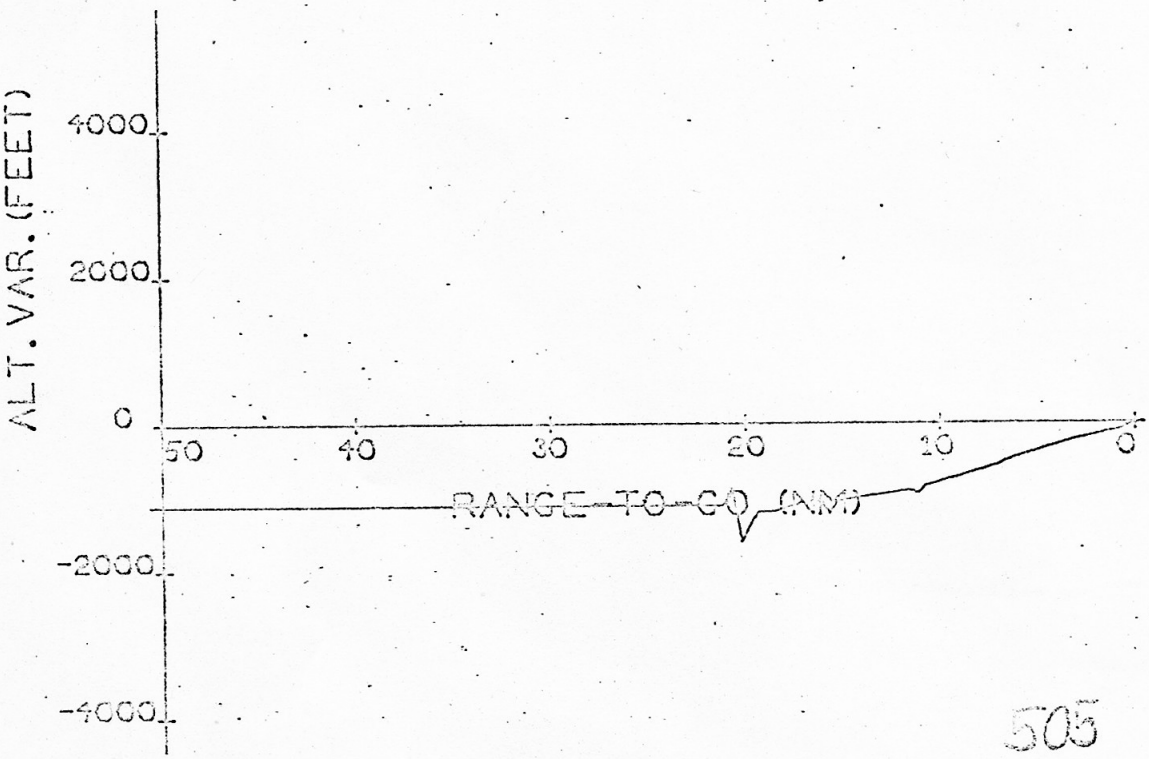

LR Beam Angles wrt Onboard Boresights, Nominal
BEAM #1 =
BEAM #2 =
BEAM #3 =
BEAM #4 =
AB-ABL (DEG)
30
20
10
0
-10
-20
-30
-40
-50
-60
200
300
400
500
600
TIME (SEC)
TIME (SEC)
BAK DEG
RUN NO. =505

DELH for Error-Free Case II-P-6 Profile 3
1-Deg. Slope

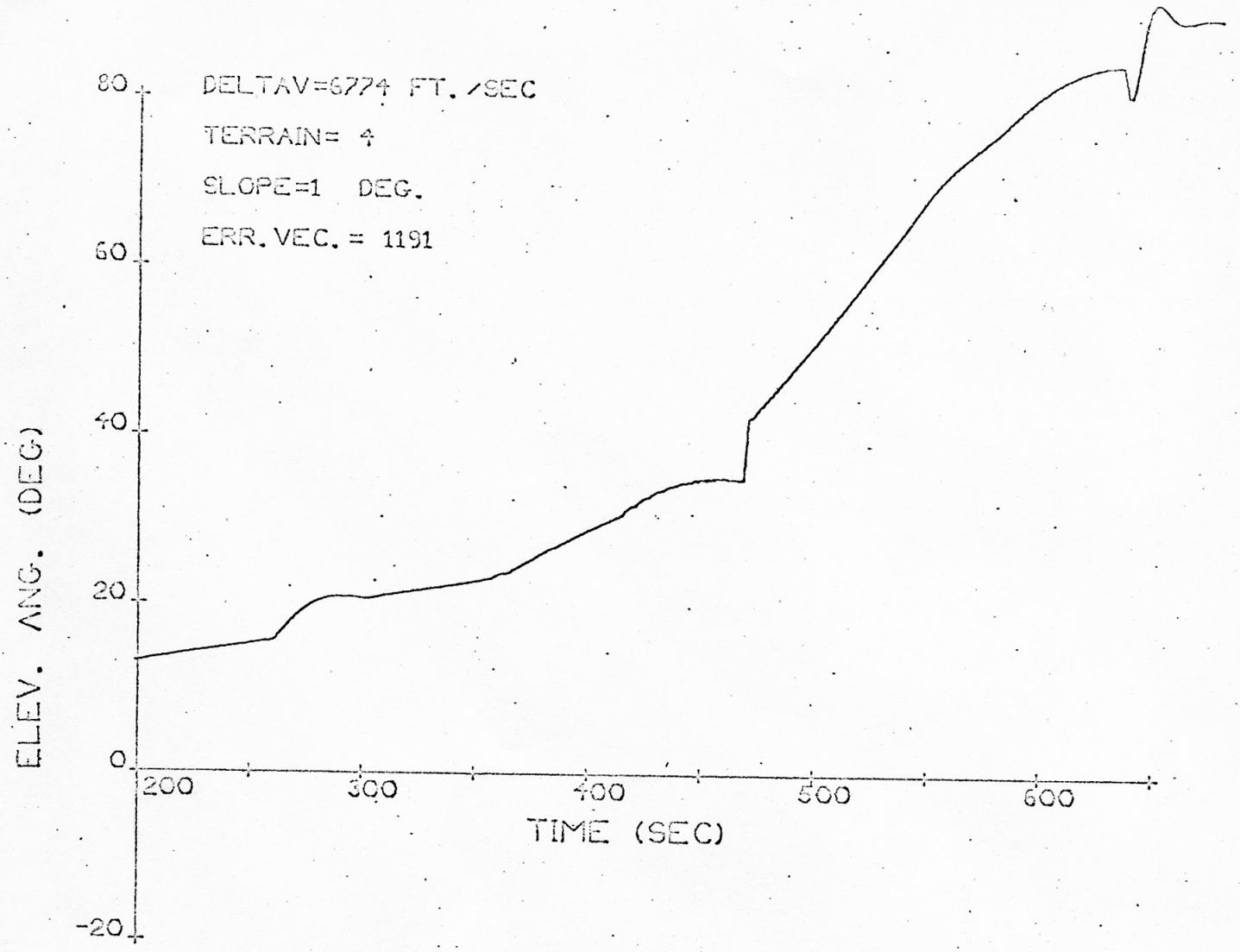


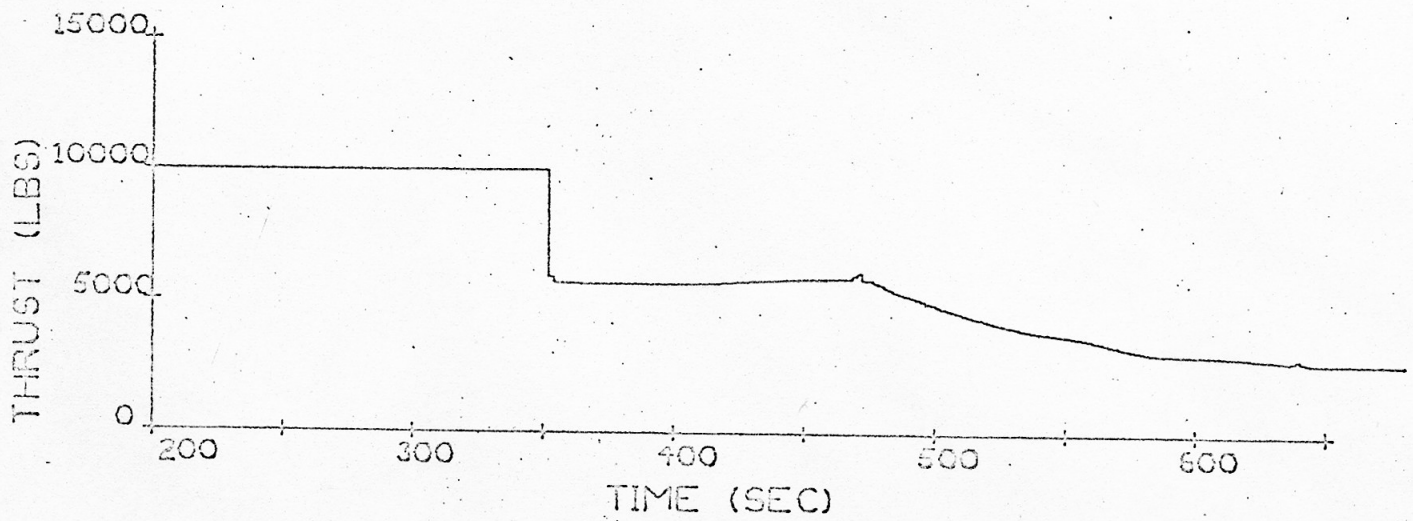
Displacement of LR Beams from Dropout Boundaries





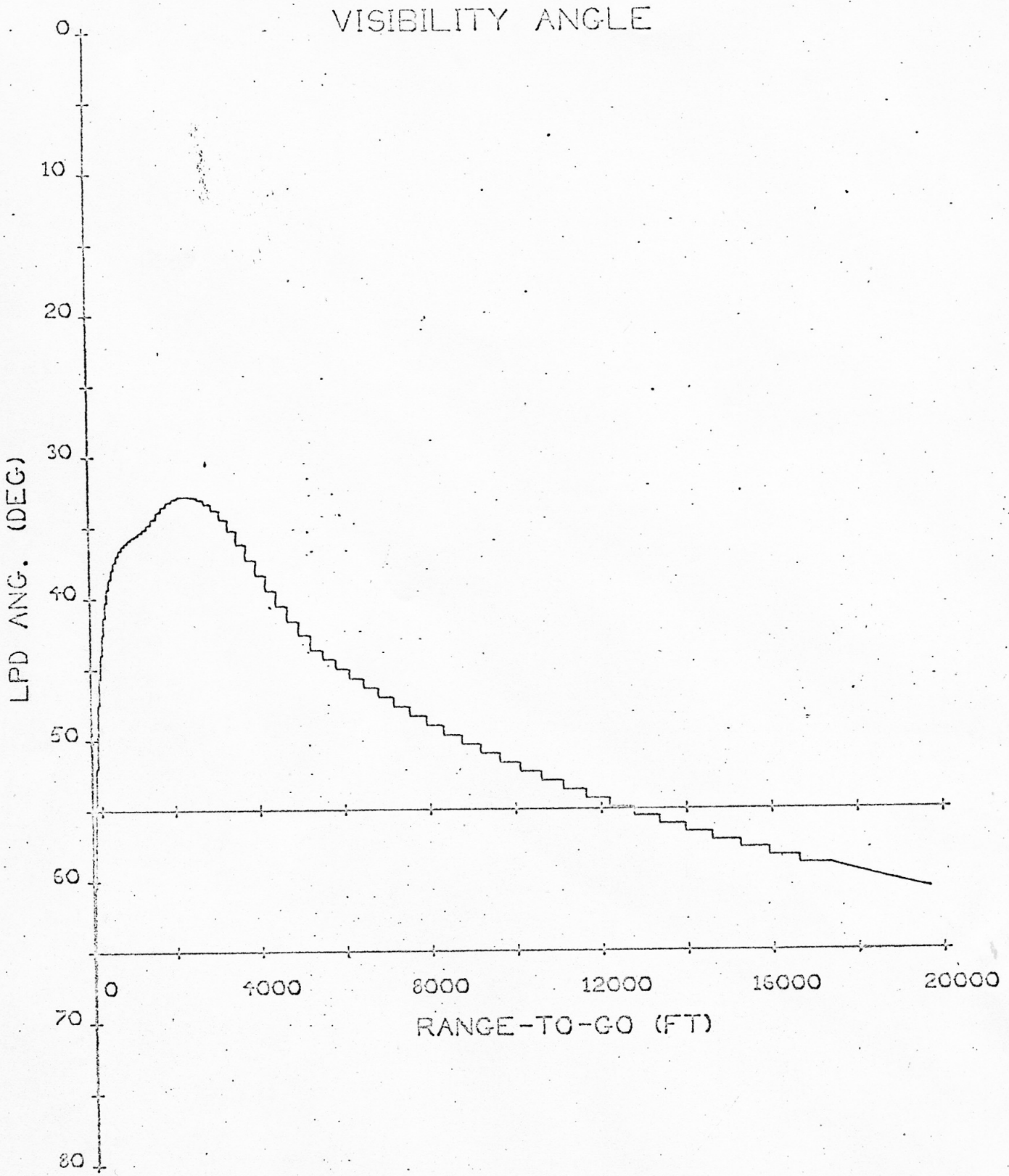
505



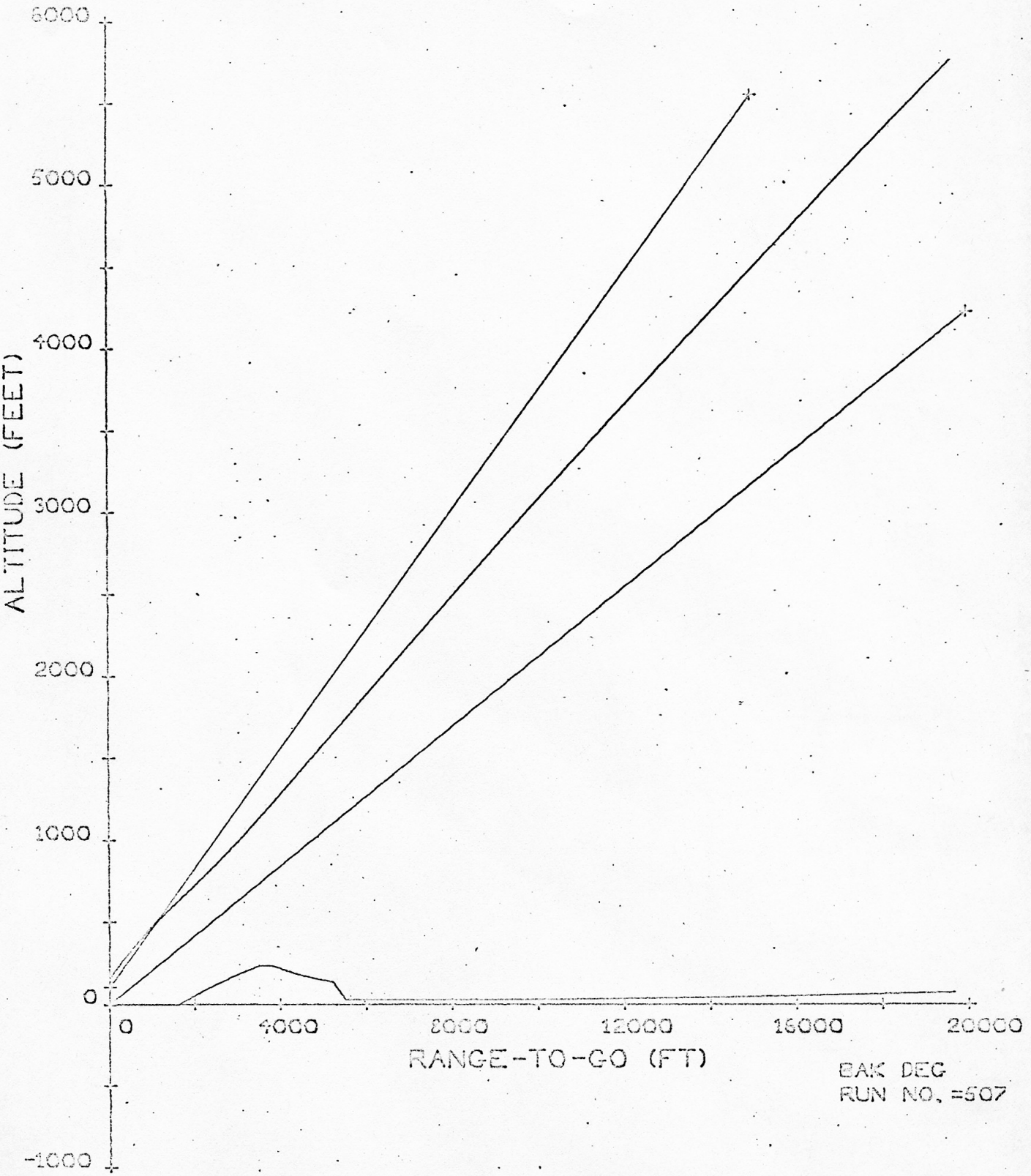


BAK DEG
RUN NO. =507

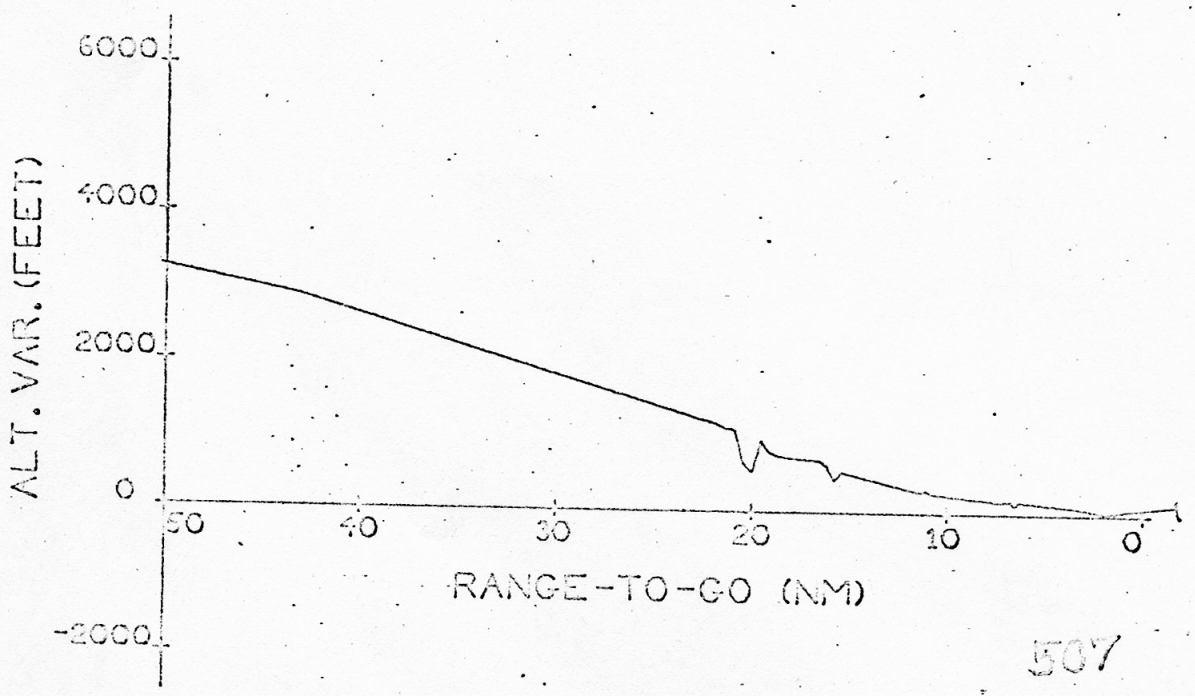
VISIBILITY ANGLE



BAK DEG
RUN NO. =507


6000
5000
4000
3000
2000
1000
0
-1000
ALTITUDE (FEET)
0
4000
8000
12000
16000
20000
RANGE-TO-GO (FT)
BAK DEC
RUN NO. =507

II-P-6 Profile 3, + 4 Deg. Slope



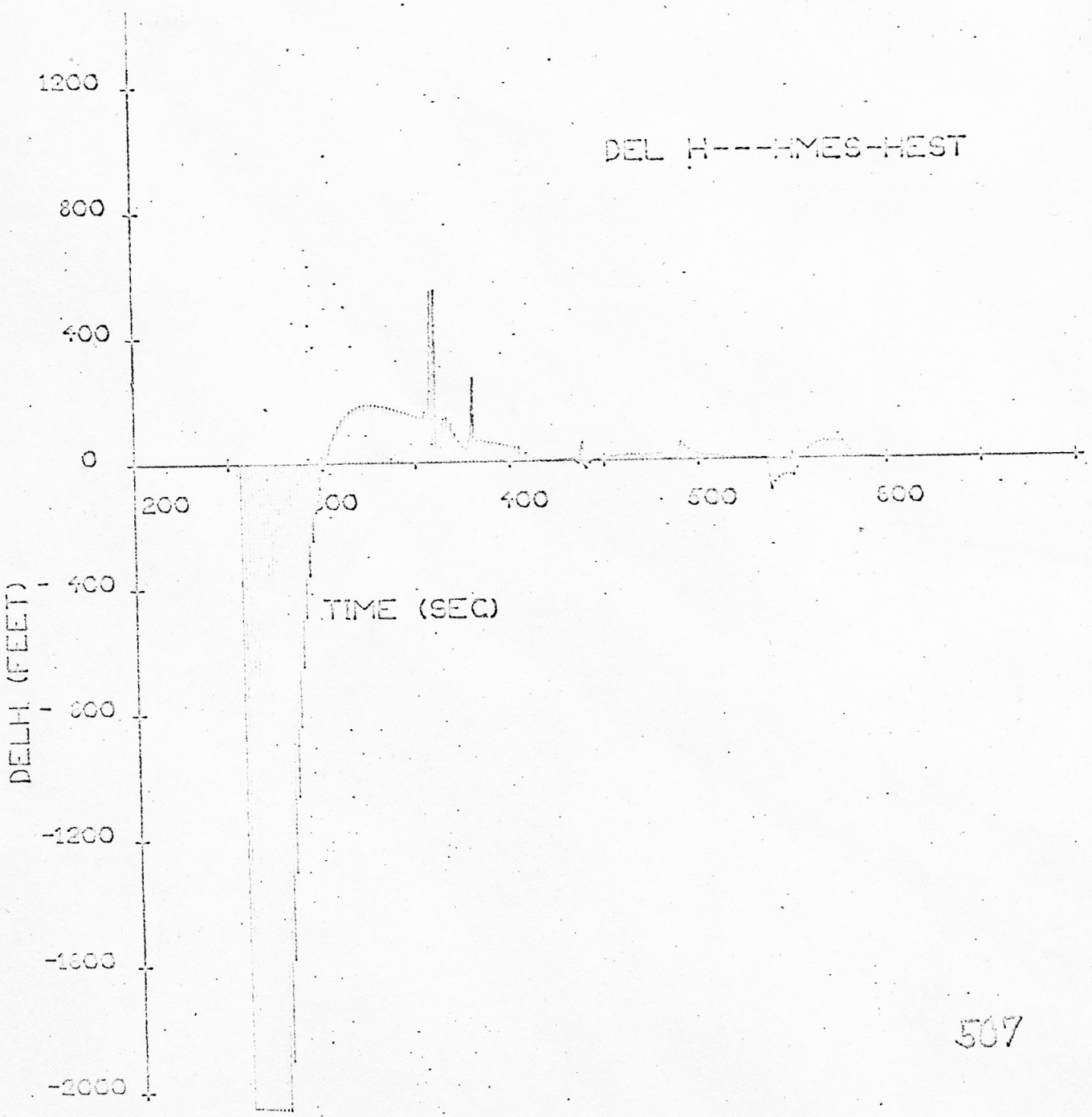
507

DELH vs. Time : I-P-6 Profile 3, Inclination

Initial Est. Errors -- Velocity Low and down range

1-sigma LR & INU bias errors.

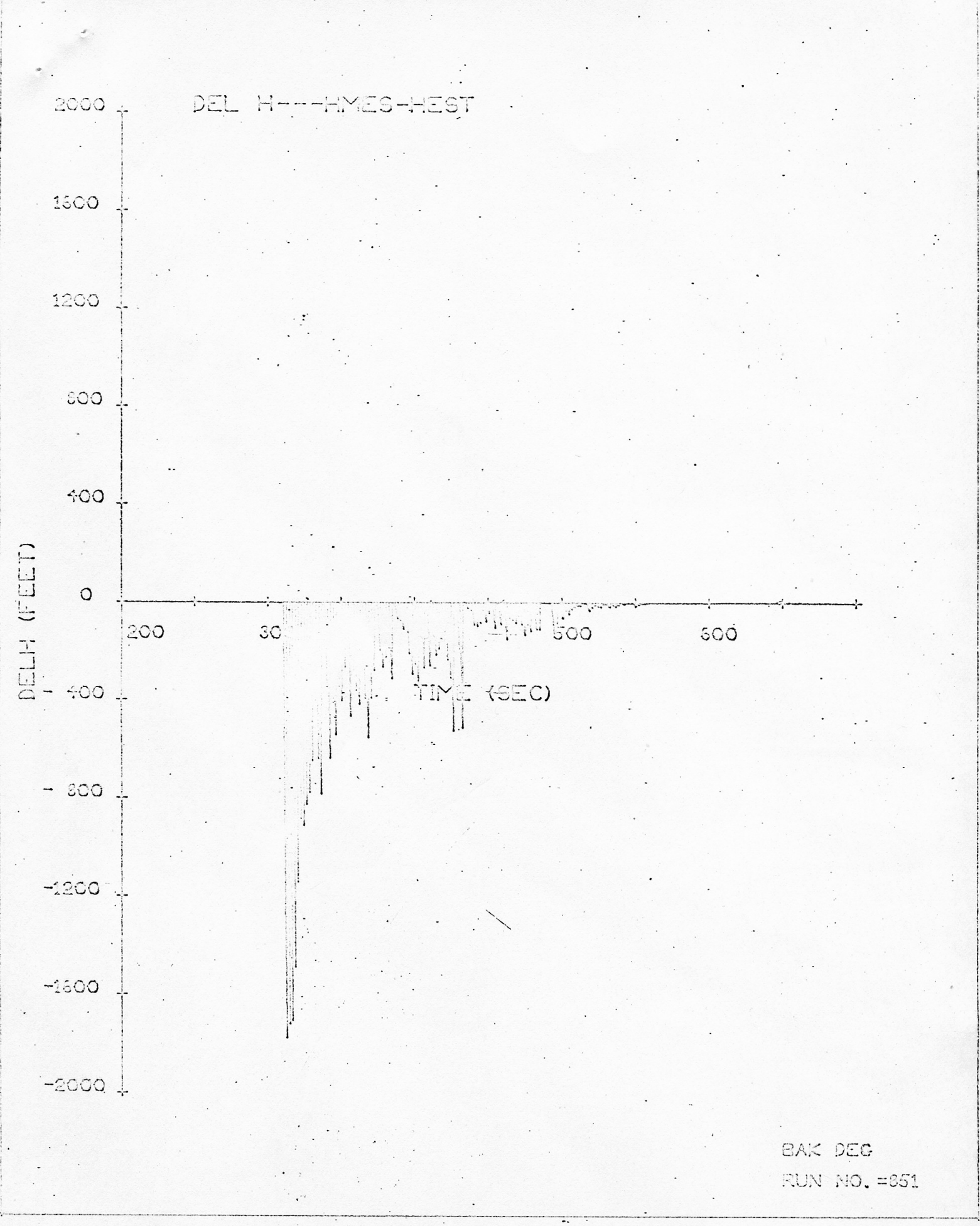
Thrust acc. +-1% at FTP

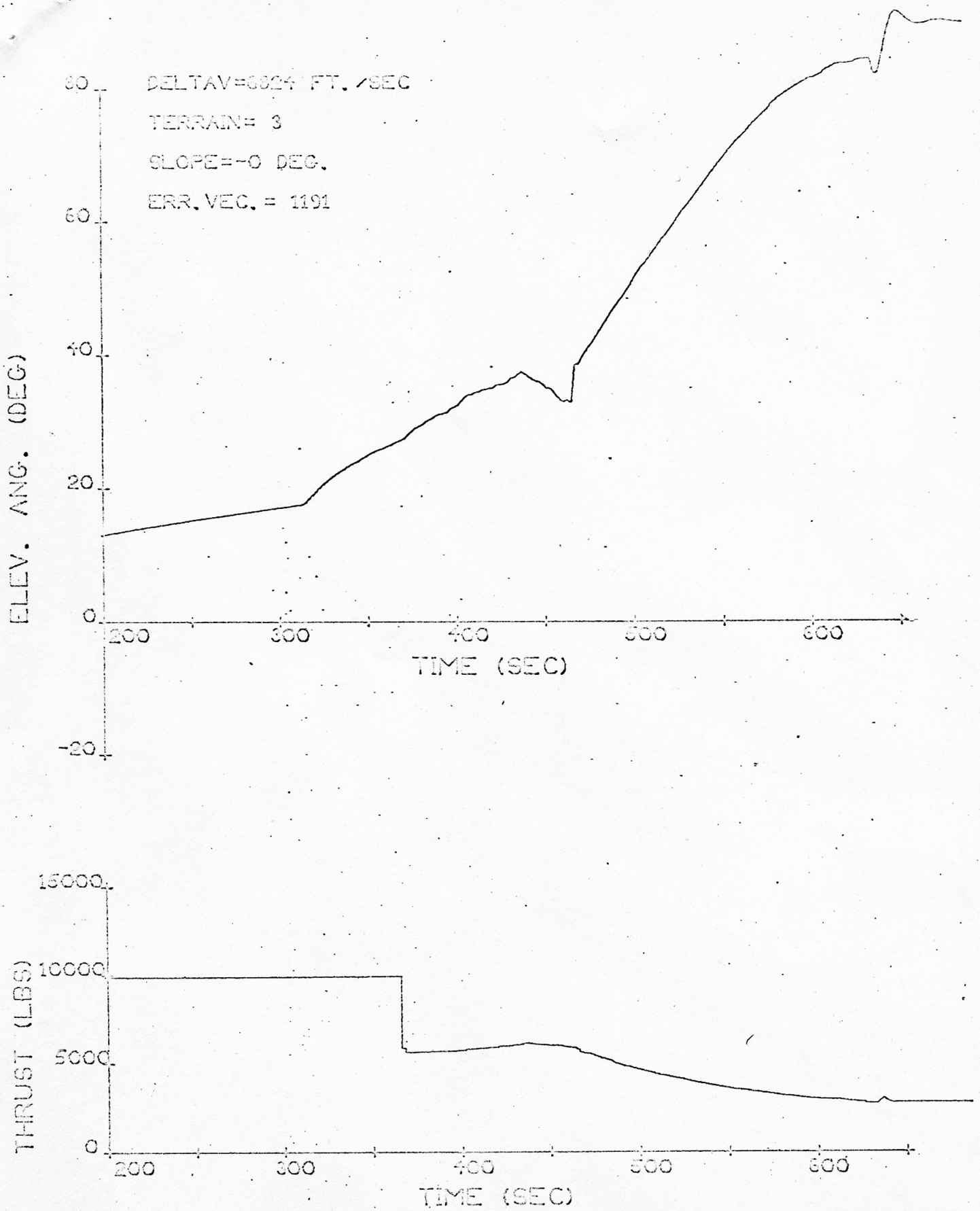


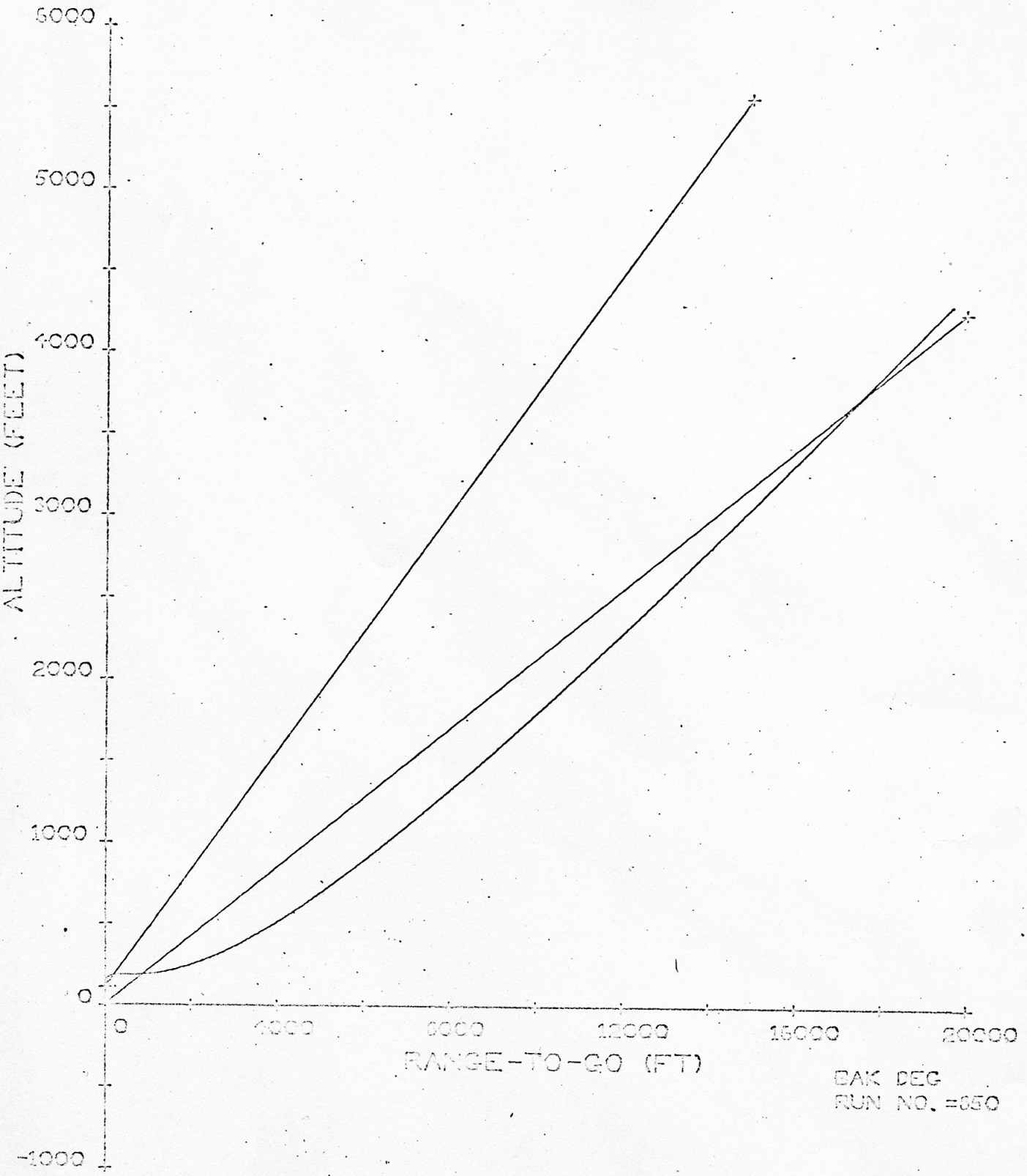
Summary of Simulated Landings

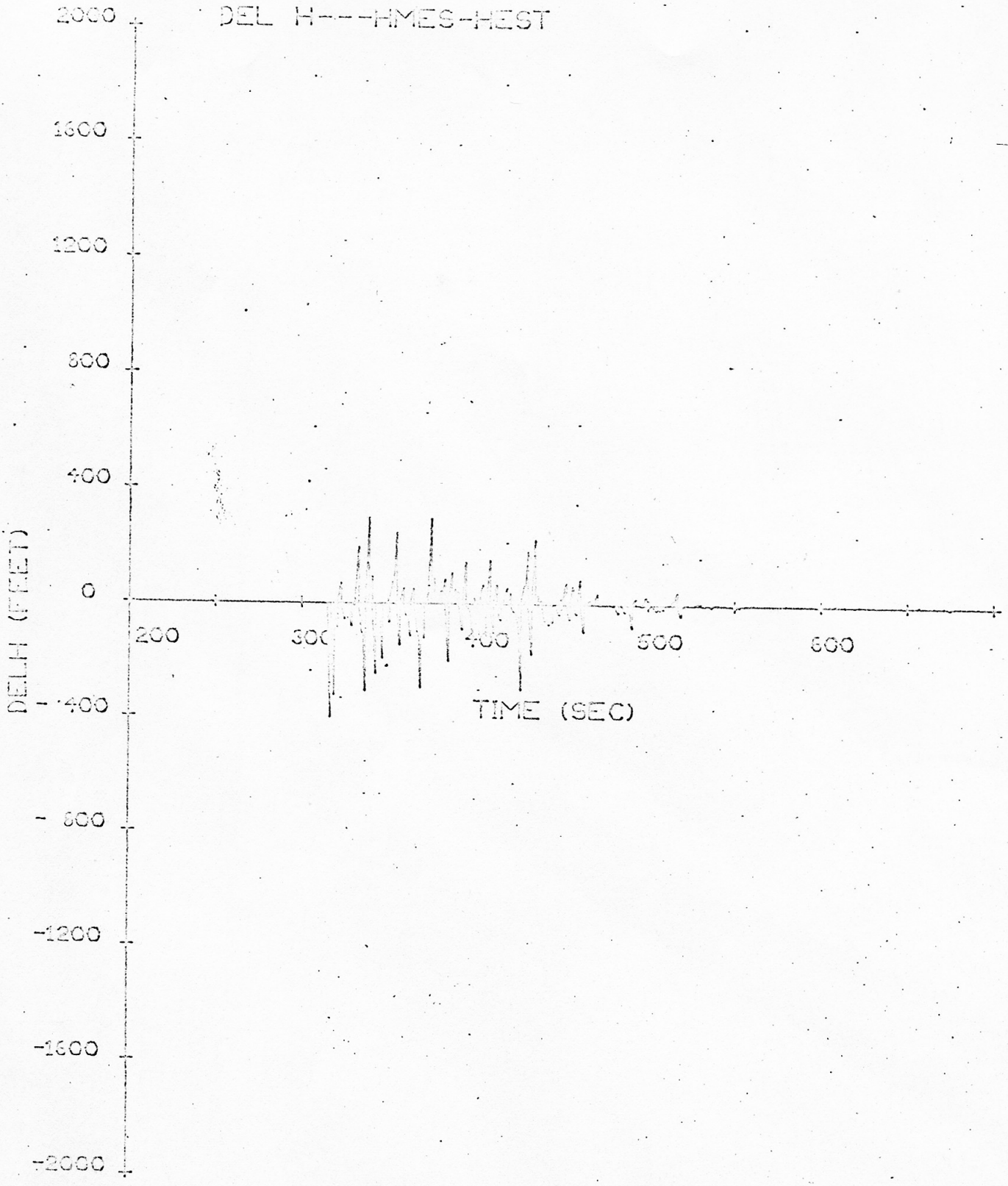
Terminal Errors in Ft. and Ft/s

Description	ΔF (m)	[illegible] (σ's)	[illegible]	Terminal Errors [illegible]	[illegible]	[illegible]	ΔV Really	Site/[illegible]	[illegible] Interval	[illegible]
1) [illegible] nominal II-1 Profile 3	0	0	—	—	—	—	—	18,000	138	
2) 1-Sigma I.C, IMU, & LR errors, Site II-P-6 File 3	+1/2	+1 sig	IMU	[illegible]	5701	.4	+537 fps	15,100	[illegible]	702
	−1			−1020	5700	1.5	−129	15,900	136	703
	+1	−1	IMU	−16[illegible]	5760	.3	+63	16,100	140	700
	−1			[illegible]	5390	.7	−101	15,000	132	701
	+1	+1	−IMU	9540	−7335	1.0	+45	18,100	140	706
	−1			9030	−7115	.9	−64	18,600	142	707
	+1	−1	−IMU	—	—	—	Crash	—	—	704
	−1							21,000	150	705
3) Same as 2) for Site II-P-2 Profile 1	0	+1	IMU	−10,[illegible]	5300	.5		15,[illegible]	136	727
	0	−1		−1020	5790	.7		16,000	138	728
	0	+1	−IMU	[illegible]	[illegible]	.6		16,[illegible]	134	725
	0	−1		9820	−7700	.5		14,500	141	726


DEL H---HYES-HEST
2000
1600
1200
800
400
0
-400
-800
-1200
-1600
-2000
200
300
500
600
DELH (FEET)
TIME (SEC)
BAK DEG
RUN NO. =851

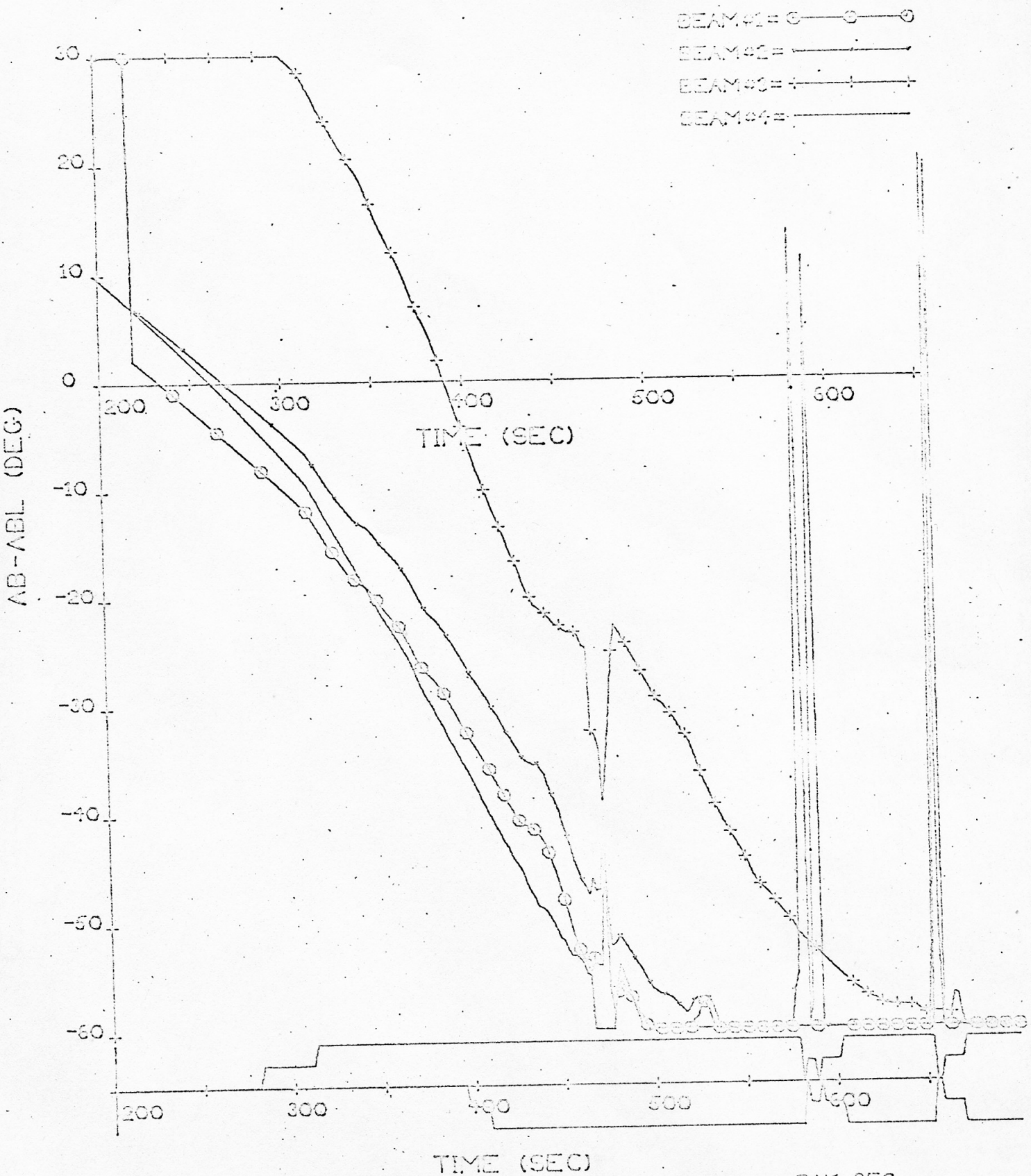

DELTAV=6824 FT./SEC
TERRAIN= 3
SLOPE=-0 DEG.
ERR.VEC. = 1191
80
60
40
20
0
-20
ELEV. ANG. (DEG)
200
300
400
500
600
TIME (SEC)
15000
10000
5000
0
THRUST (LBS)
200
300
400
500
600
TIME (SEC)
BAK DEG
RUN NO. =851

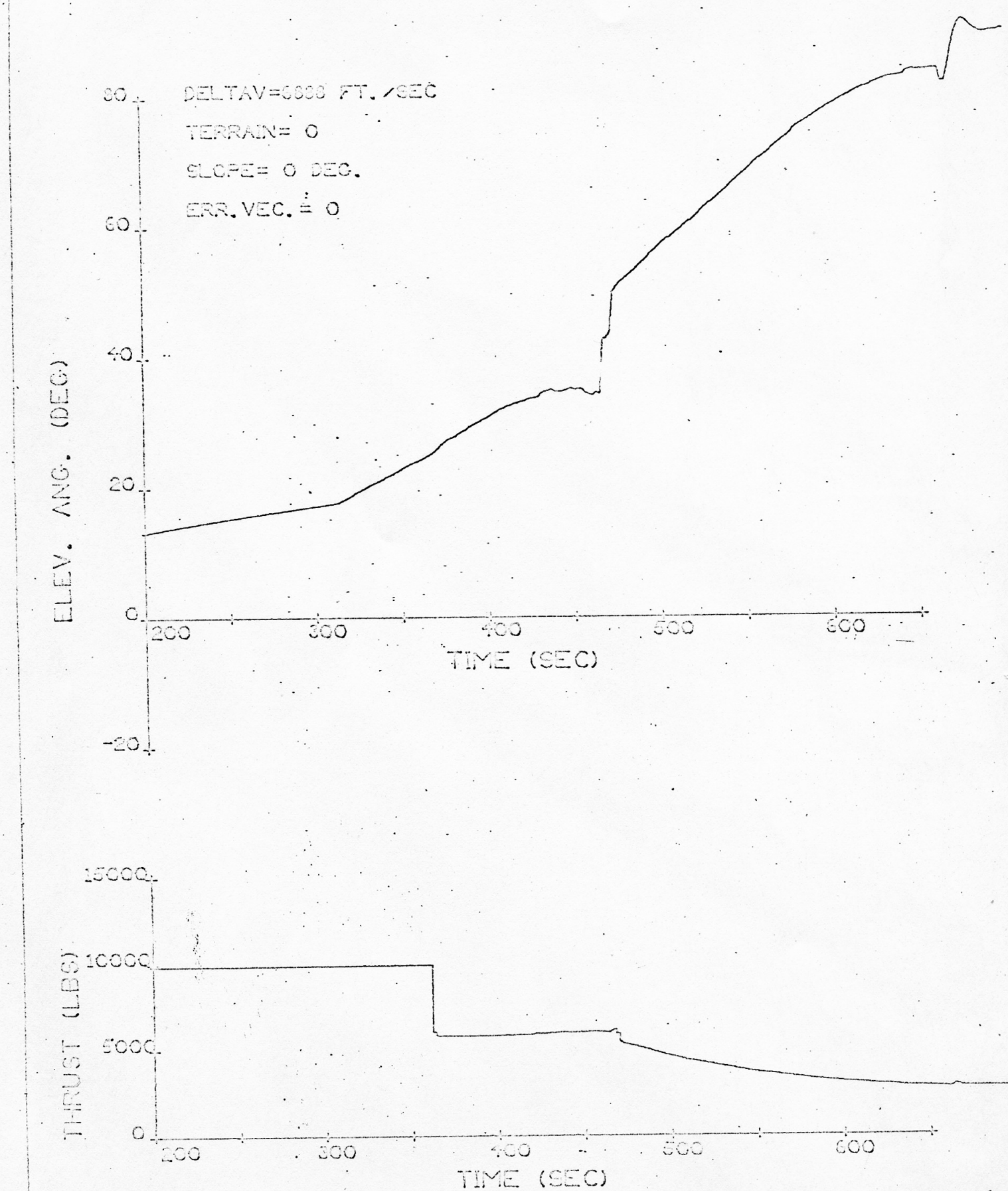

6000
5000
4000
3000
2000
1000
0
-1000
ALTITUDE (FEET)
0
3000
6000
9000
12000
15000
18000
RANGE-TO-GO (FT)
BAK DEG
RUN NO. =050

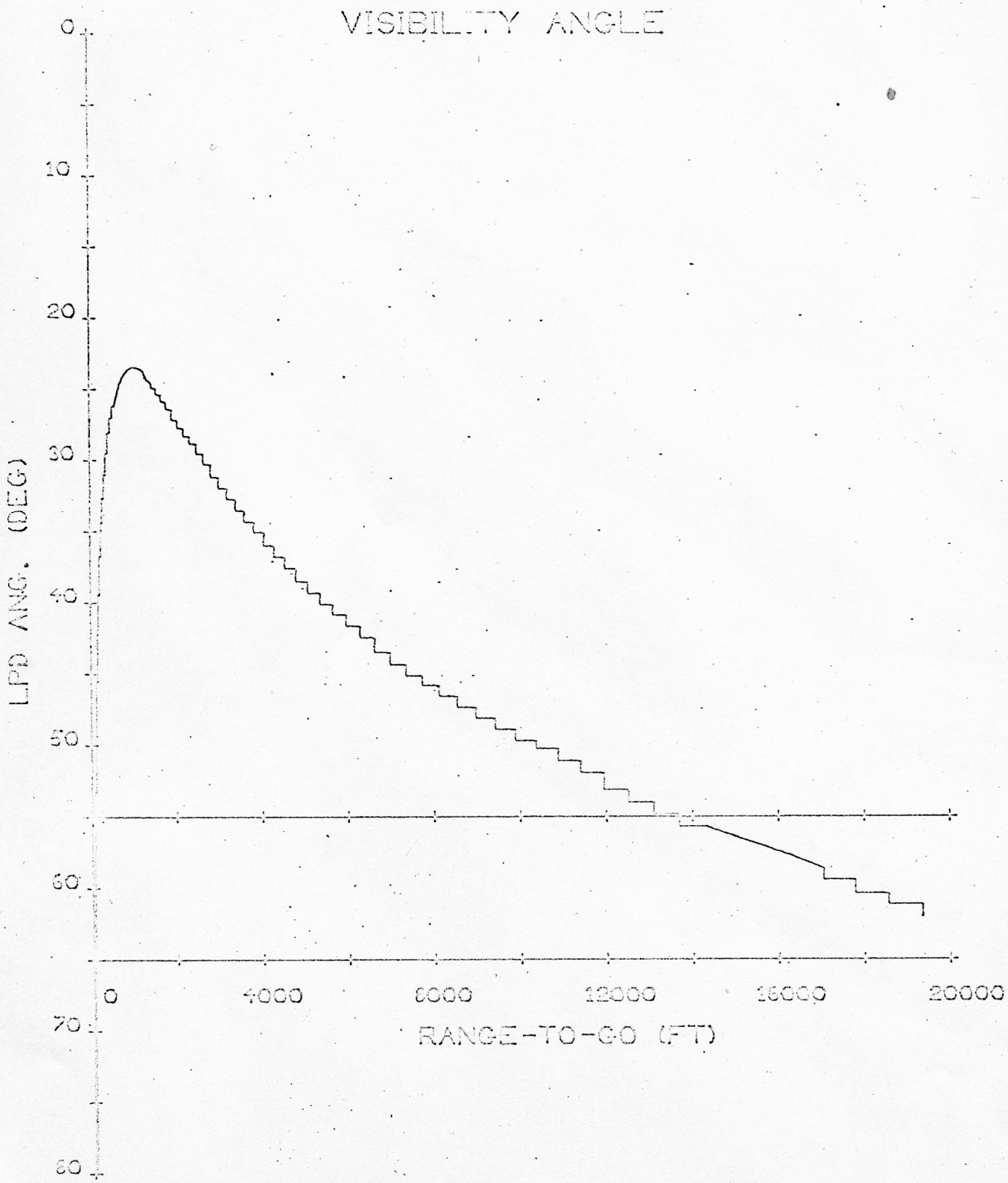


BAK DEC

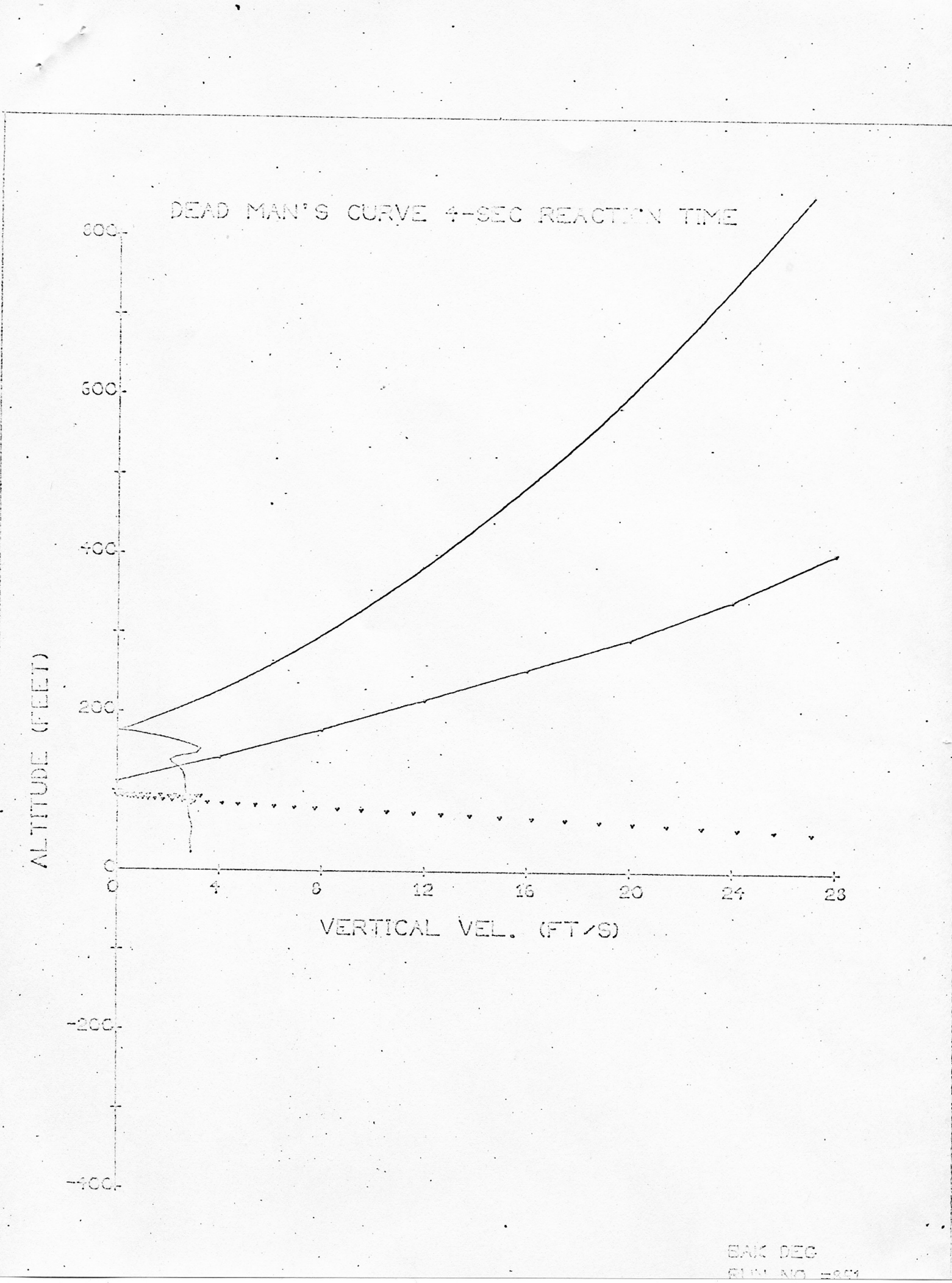
RUN NO. =850

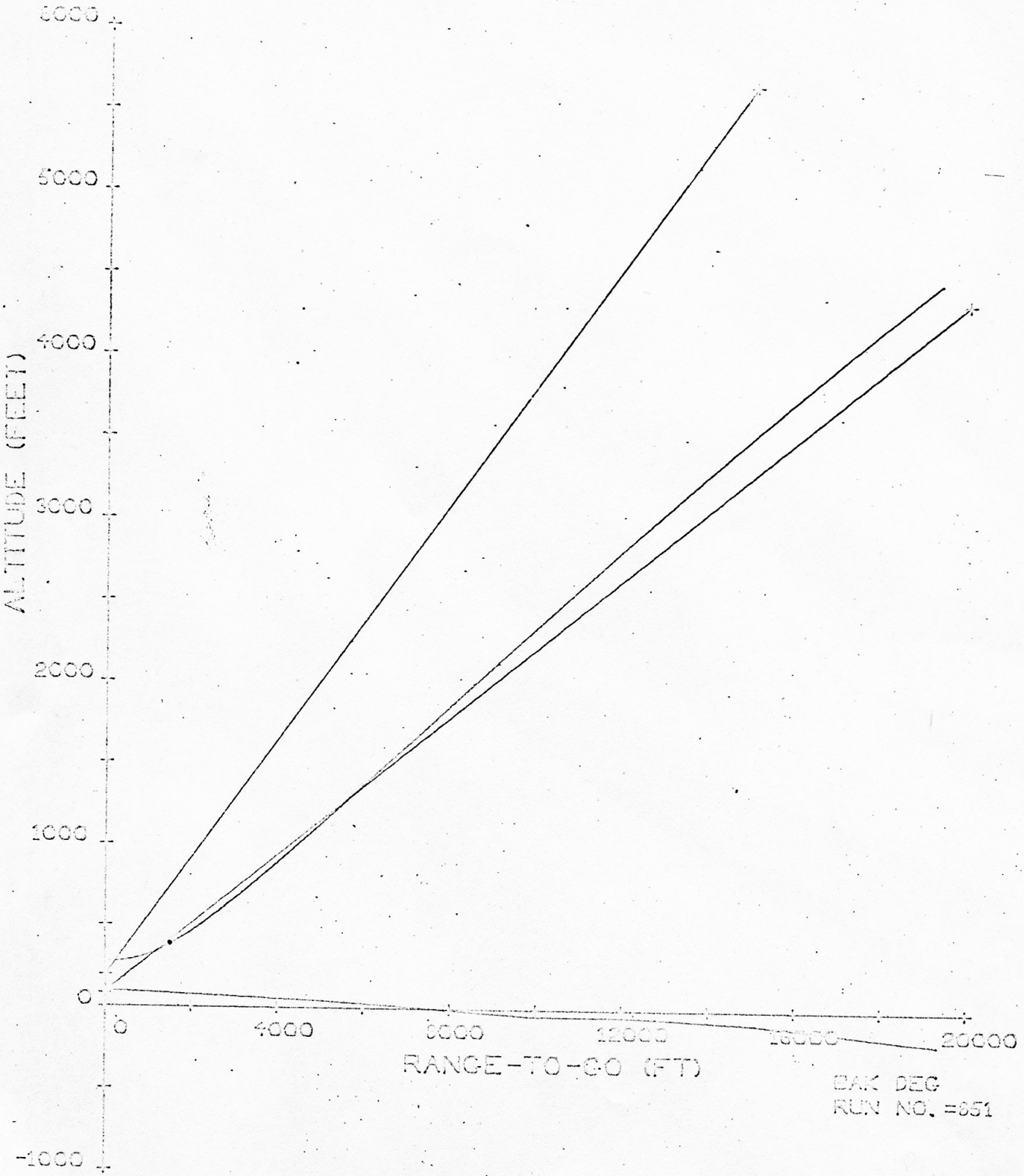

BEAM #1 =
BEAM #2 =
BEAM #3 =
BEAM #4 =
30
20
10
0
-10
-20
-30
-40
-50
-60
200
300
400
500
600
TIME (SEC)
AB-ABL (DEG)
200
300
400
500
600
TIME (SEC)
BAK DEG
RUN NO. =650

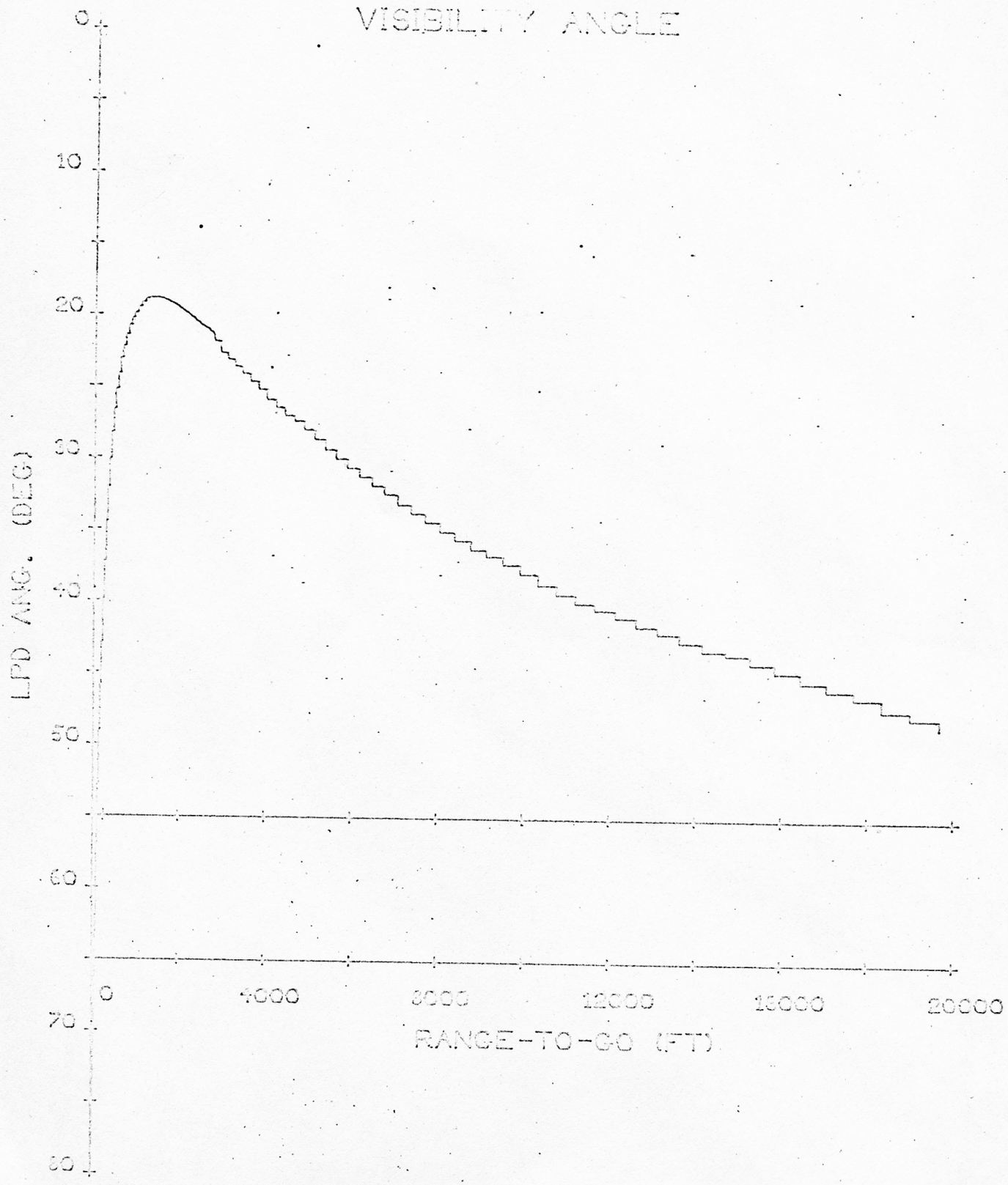

DELTAV=6800 FT./SEC
TERRAIN= 0
SLOPE= 0 DEG.
ERR.VEC.= 0
80
60
40
20
0
-20
ELEV. ANG. (DEG)
200
300
400
500
600
TIME (SEC)
15000
10000
5000
0
THRUST (LBS)
200
300
400
500
600
TIME (SEC)
BAK DEG
RUN NO. =850



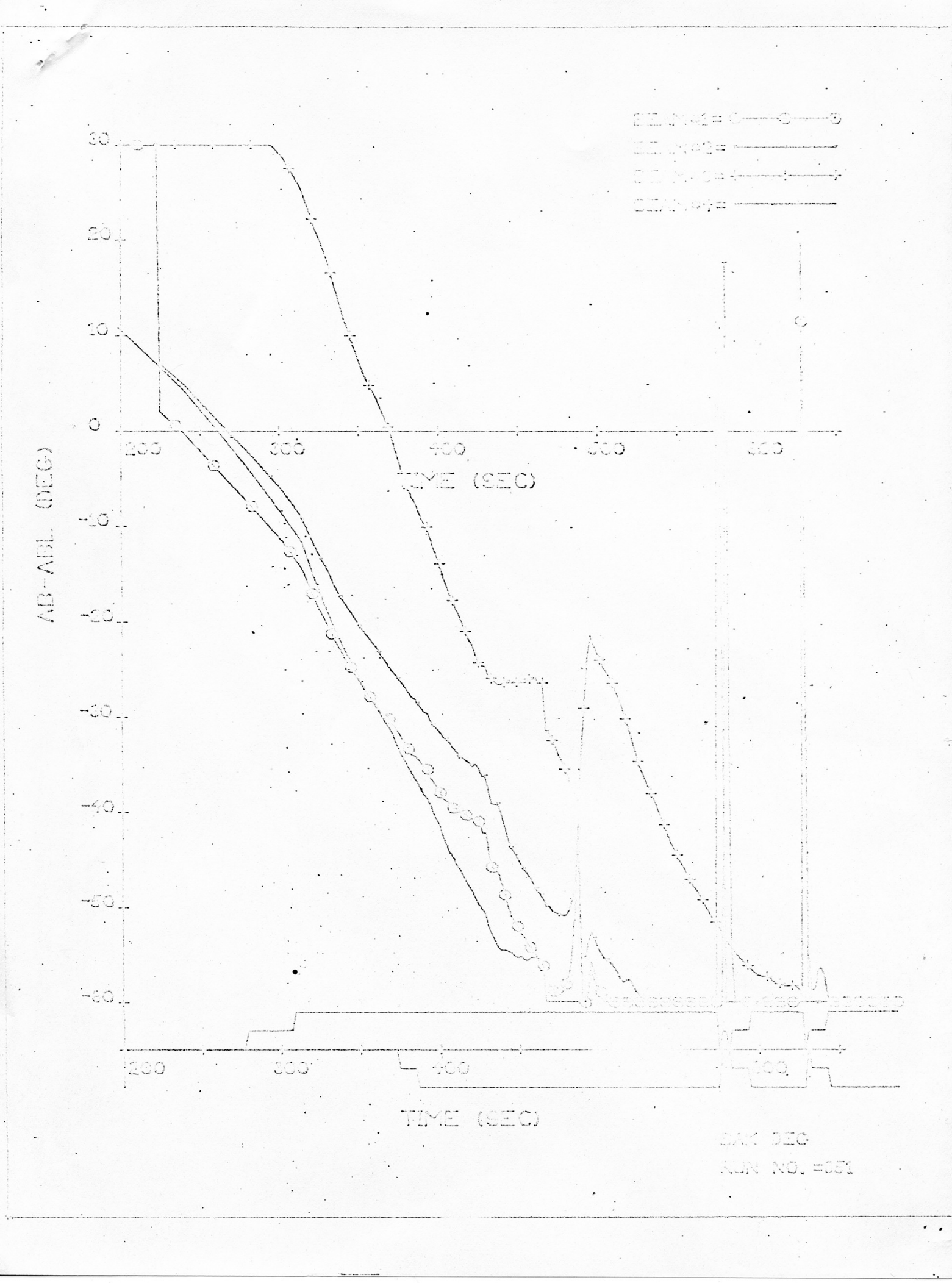
BANK DEG
RUN NO. =051


DEAD MAN'S CURVE 4-SEC REACTION TIME
800
600
400
200
0
-200
-400
ALTITUDE (FEET)
0
4
8
12
16
20
24
28
VERTICAL VEL. (FT/S)
BANK DEC


6000
5000
4000
3000
2000
1000
0
-1000
ALTITUDE (FEET)
0
4000
8000
12000
16000
20000
RANGE-TO-GO (FT)
BAK DEG
RUN NO. =851


VISIBILITY ANGLE
0
10
20
30
40
50
60
70
80
LPD ANG. (DEG)
0
4000
8000
12000
16000
20000
RANGE-TO-GO (FT)

BANK DEG


30
20
10
0
-10
-20
-30
-40
-50
-60
200
300
400
500
600
TIME (SEC)
AB-ABL (DEG)
TIME (SEC)
DAY DEG
RUN NO. =021